US005801707A

United States Patent [19]

Rolnik et al.

[11] Patent Number: 5,801,707

[45] Date of Patent: Sep. 1, 1998

[54] **METHOD AND APPARATUS FOR DISPLAYING HIERARCHICAL DATA ASSOCIATED WITH COMPONENTS OF A SYSTEM**

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[73] Assignee: **Motorola, Inc.**, Schaumburg, Ill.

[21] Appl. No.: **684,599**

[22] Filed: **Jul. 19, 1996**

[51] **Int. Cl.**[6] **G06F 13/00**

[52] **U.S. Cl.** **345/429**

[58] **Field of Search** 395/329, 330, 395/333, 331, 118, 355, 356, 357

[56] **References Cited**

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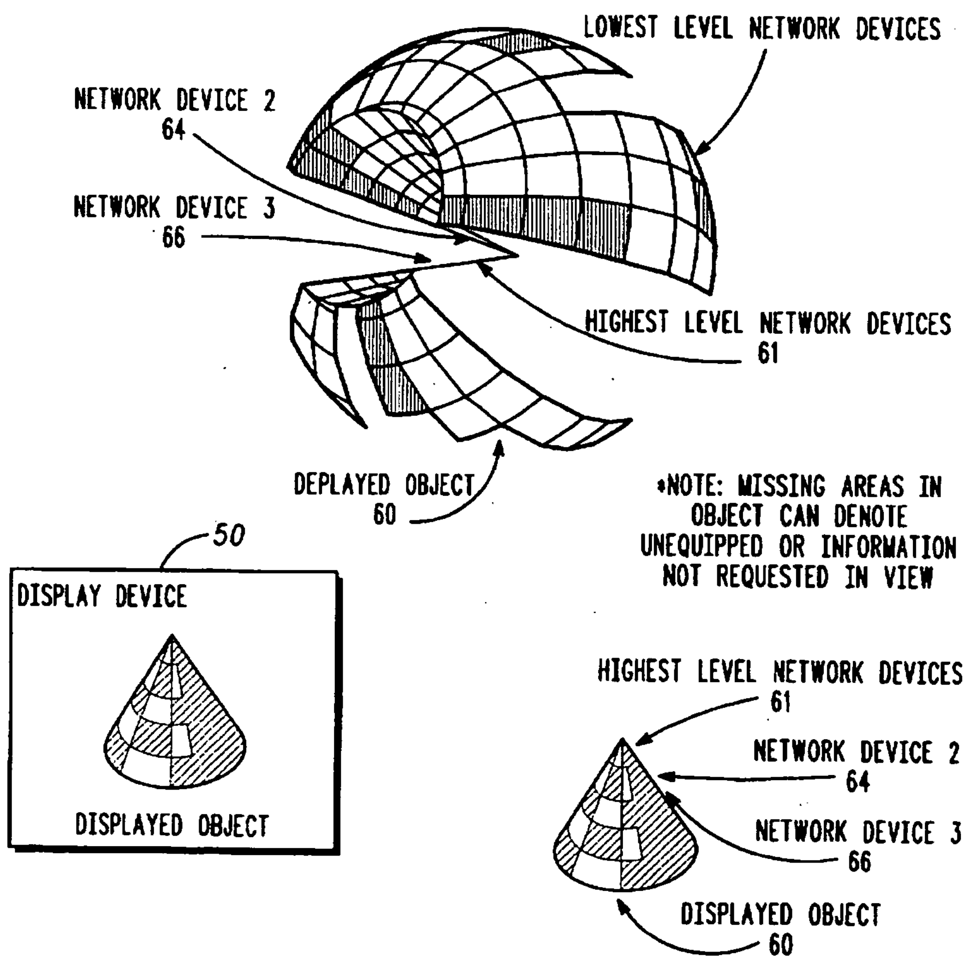
Primary Examiner—Phu K. Nguyen
Assistant Examiner—Cliff N. Vo

[57] **ABSTRACT**

A method of displaying hierarchical data. The method includes the steps of: retrieving hierarchical network data and displaying the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements. Each data element is associated with a network device. An apparatus for displaying hierarchical data is provided. The apparatus comprises a display device, a memory device storing the hierarchical data, and a processor responsive to the memory. The processor includes a graphical display module that displays the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements where each data element is associated with a network device;

15 Claims, 4 Drawing Sheets



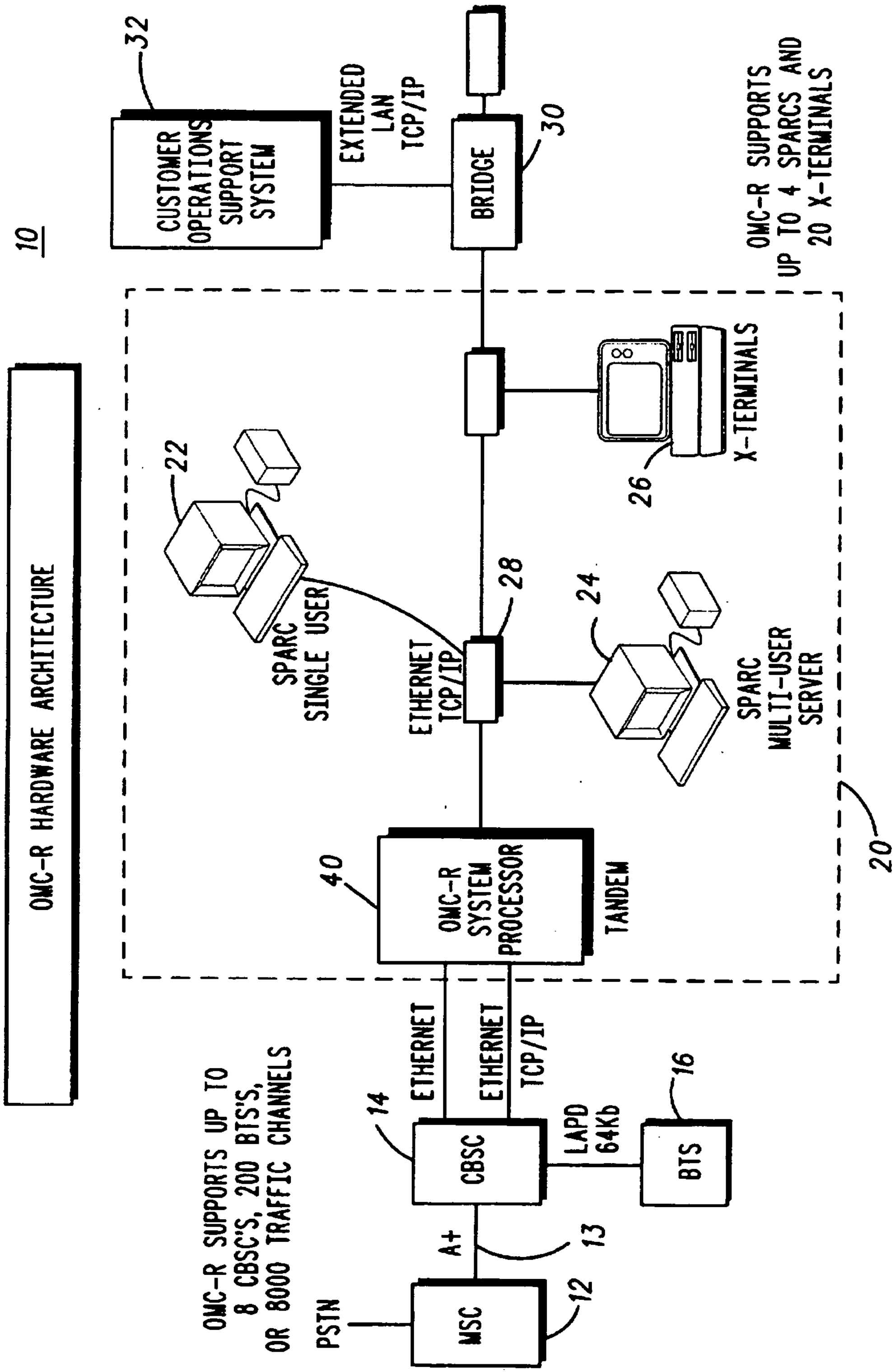
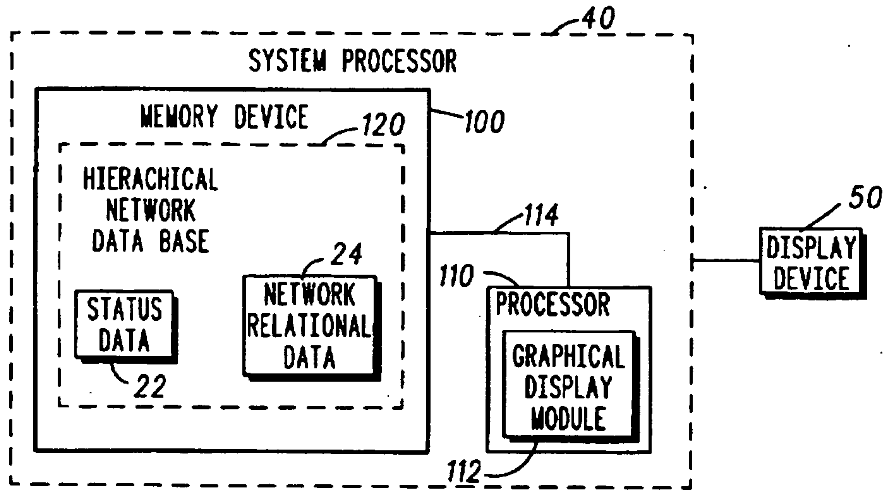
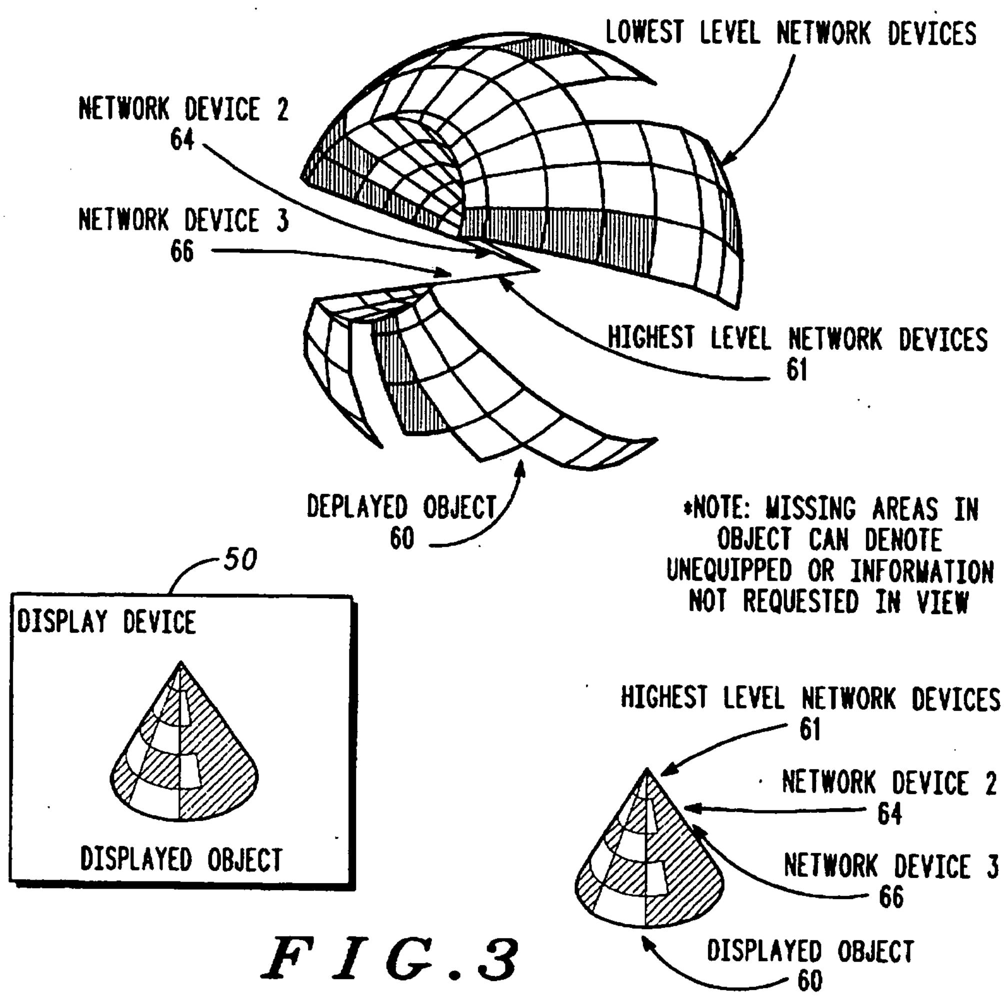

10
OMC-R HARDWARE ARCHITECTURE
CUSTOMER OPERATIONS SUPPORT SYSTEM
32
EXTENDED LAN TCP/IP
BRIDGE
30
OMC-R SUPPORTS UP TO 4 SPARCS AND 20 X-TERMINALS
22
SPARC SINGLE USER
ETHERNET TCP/IP
28
24
SPARC MULTI-USER SERVER
26
X-TERMINALS
40
OMC-R SYSTEM PROCESSOR
TANDEM
20
ETHERNET
ETHERNET
TCP/IP
OMC-R SUPPORTS UP TO 8 CBSC'S, 200 BTS'S, OR 8000 TRAFFIC CHANNELS
14
CBSC
LAPD 64Kb
16
BTS
A+
13
PSTN
MSC
12

FIG. 1


40
SYSTEM PROCESSOR
MEMORY DEVICE
100
120
HIERACHICAL NETWORK DATA BASE
24
STATUS DATA
22
NETWORK RELATIONAL DATA
114
110
PROCESSOR
GRAPHICAL DISPLAY MODULE
112
50
DISPLAY DEVICE

F I G. 2


LOWEST LEVEL NETWORK DEVICES
NETWORK DEVICE 2
64
NETWORK DEVICE 3
66
HIGHEST LEVEL NETWORK DEVICES
61
DEPLAYED OBJECT
60
*NOTE: MISSING AREAS IN OBJECT CAN DENOTE UNEQUIPPED OR INFORMATION NOT REQUESTED IN VIEW
50
DISPLAY DEVICE
DISPLAYED OBJECT
HIGHEST LEVEL NETWORK DEVICES
61
NETWORK DEVICE 2
64
NETWORK DEVICE 3
66
DISPLAYED OBJECT
60

F I G. 3

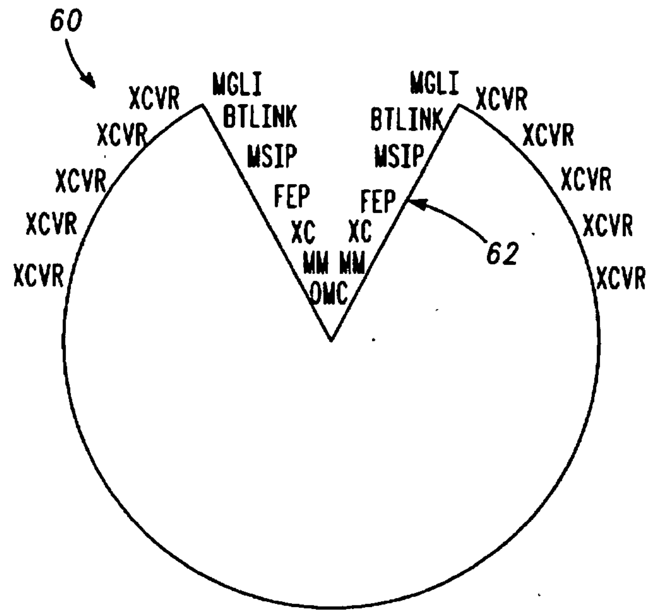
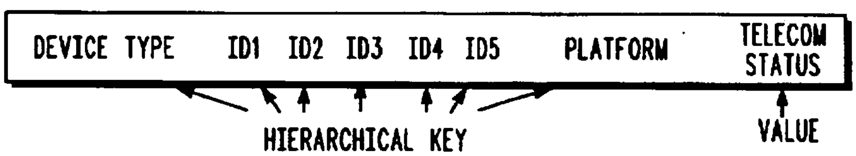


FIG.4

EXAMPLE OBJECT REPRESENTING A DATA
ELEMENT PRESENTED IN THE DISPLAY




```
ABSTRACT CLASS LOGICAL DEVICE
 {
    RC   INT   DEVTYPE;   // THE DEVICE TYPE
    RC   INT   ID1;       // HIERARCHICY INFORMATION
    RC   INT   ID2;       // HIERARCHICY INFORMATION
    RC   INT   ID3;       // HIERARCHICY INFORMATION
    RC   INT   ID4;       // HIERARCHICY INFORMATION
    RC   INT   ID5;       // HIERARCHICY INFORMATION
    RC   INT   PLATFORM;  // TELECOM PLATFORM
    RW   INT   TELSTATUS; // TELCOM STATUS
  // OPERATIONS
    CONTROLLER Status Update (IN INT aNewTelphonyStatus);
    CONTROLLER StatusReport(out int CuTelphonyStatus);
  );
```

FIG.5

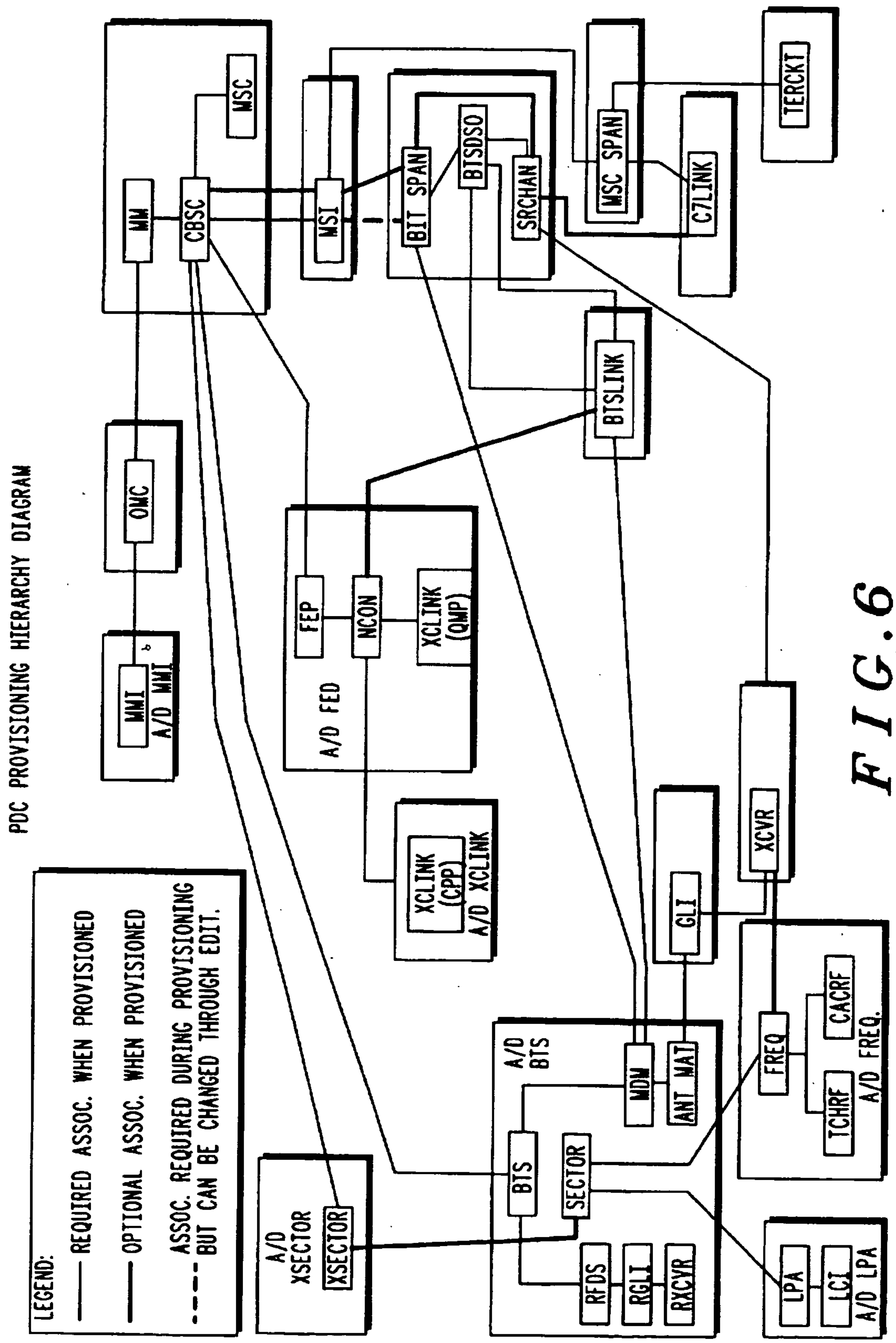

PDC PROVISIONING HIERARCHY DIAGRAM
LEGEND:
REQUIRED ASSOC. WHEN PROVISIONED
OPTIONAL ASSOC. WHEN PROVISIONED
ASSOC. REQUIRED DURING PROVISIONING BUT CAN BE CHANGED THROUGH EDIT.
MM
CBSC
MSC
MSI
BIT SPAN
BTSDSO
SRCHAN
MSC SPAN
C7LINK
TERCKT
BTSLINK
OMC
MMI
A/D MMI
FEP
NCON
XCLINK (QMP)
A/D FED
XCLINK (CPP)
A/D XCLINK
XCVR
GLI
A/D BTS
MDM
ANT MAT
BTS
SECTOR
RFDS
RGLI
RXCVR
FREQ
CACRF
TCHRF
A/D FREQ.
LPA
LCI
A/D LPA
A/D XSECTOR
XSECTOR

FIG. 6

METHOD AND APPARATUS FOR DISPLAYING HIERARCHICAL DATA ASSOCIATED WITH COMPONENTS OF A SYSTEM

FIELD OF THE INVENTION

This invention relates generally to complex systems, and more particularly to displaying hierarchical data associated with components of such systems.

BACKGROUND OF THE INVENTION

Complex systems with many components, such as cellular systems, generally require a high degree of maintenance. In order to manage the maintenance of each of the components, an operations center with a display representing various status indicators of the components is usually provided. Conventional systems typically generate reports such as alarm or traffic reports to provide system operators information regarding the operation of the system. Although these reports provide valuable information regarding specific aspects of the system, they fail to adequately provide an overall view of the system. More recently, improved display devices and operations centers use graphical user interfaces. Such graphical user interfaces typically display two-dimensional geographical information, such as a cell site view for a cellular communication system. However, due to the increased complexity of modern communication systems, there is still a need to display a high level view of the entire system. Such a high level view would allow trouble spots to be more quickly detected and acted upon.

Accordingly, there is a need for an improved method and apparatus for displaying data associated with components of a complex system.

SUMMARY OF THE INVENTION

In order to address this need, the present invention provides a method of displaying hierarchical data. The method includes the steps of retrieving hierarchical network data and displaying the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements where each data element is associated with a network device.

In accordance with another aspect of the invention, an apparatus for displaying hierarchical data is provided. The apparatus comprises a display device, a memory device storing the hierarchical data, and a processor responsive to the memory. The processor includes a graphical display module that displays the hierarchical network data using a perspective three dimensional view. The hierarchical data includes a plurality of data elements where each data element is associated with a network device.

The invention itself, together with its intended advantages will best be understood by reference to the following detailed description, taken in conjunction with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram depicting a cellular system that may use an embodiment of the present invention.

FIG. 2 is a block diagram of the system processor and display device of FIG. 1.

FIG. 3 and FIG. 4 are diagrams of an object displayed by the display device of FIG. 2.

FIG. 5 is a diagram of a hierarchical data element definition used by the objects in FIGS. 3 and 4.

FIG. 6 is a diagram of a hierarchical network that may be displayed by the object of FIGS. 3 and 4.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

Referring to FIG. 1, a communication system 10 including a plurality of components is illustrated. Communication system 10 is a cellular communication system including a mobile switching center (MSC) 12, a base station controller (CBSC) 14, an operation maintenance center (OMC) 20, an operation support center 32, and a plurality of base transceiver stations (BTS) 16. Each of the plurality of base transceiver stations 16 is connected to the CBSC 14 via a data interface known to those of ordinary skill in the art. Similarly the MSC 12 is coupled to the CBSC 14 via a conventional cellular interface 13, such as the A plus interface. The CBSC 14 is connected to the OMC 20 via a data connection such as a TCP/IP connection. The OMC 20 is connected to the operation support system 32 via bridge 30 and via a data network such as a TCP/IP local area network. The OMC 20 includes a system processor 40, a user station 22, a multi-user station 24, a display terminal 26, and a computer network interconnection system 28. The computer network interconnection system 28 is typically a standard computer data network such as a TCP/IP ethernet network. Although both a single user station and a multi user server 22 and 24, are shown, these servers are optional.

Referring to FIG. 2, a more detailed diagram of the system processor 40 is provided. The system processor 40 includes a memory device 100 and a processor 110. The memory device 100 is coupled to the processor 110 via a bus 114. The memory device 100 includes a hierarchical network database 120 which further includes a status data memory area 122 and a network relationship data area 124. The processor 110 includes a three dimensional graphical display module 112.

In the preferred embodiment, the display module 112 includes hardware and software necessary to present the hierarchical data to the graphical display. Examples of suitable software for the display modules 112 include three dimension rending software available from Alias/Wavefront, Virtual reality modeling language (VRML), and HTML/JAVA®. JAVA® is a registered trademark of Sun Microsystems, Inc. Each of these software packages are known to those of ordinary skill in the art. Suitable hardware includes a high speed graphics monitor capable of quick three dimensional rendering which are known to those skill in the art.

The system processor 40 is connected to a display device 50 in a conventional manner. The display device 50 may be used as the display 26 within the OMC 20 or may be incorporated or attached to the operation support system 32. In any event, the display device 50 is used by operations personnel such as technicians, to control and maintain the communication system 10.

The hierarchical network data base 120, including both the status data area 122 and the network relationship data area 124, contains specific information regarding each of the components within the communication system 10. For example, many components within the base stations 16 such as transceivers, may each have an entry within the hierarchical data base 120. In addition, since each component in the communication system 10 is typically connected to one or more other components, the relationship between components is stored in the network relationship data area 124. For example, since BTS 16 is coupled to CBSC 14 a network

relationship between the BTS 16 and CBSC 14 would be stored in the network relationship data area 124. In this manner data regarding each component in the system 10 as well as the relationship between components in a hierarchical model may be stored within the hierarchical network data base 120.

Referring to FIG. 6, an example of a hierarchical network that may be implemented with a suitable database that stores the network. Many such databases are known to those of ordinary skill in the art. For illustrative purposes, an example of a database record for one element of information for one device in such a database is shown in FIG. 5. The particular database record of FIG. 5 describes the telephony status for a particular device in a cellular system.

Referring to FIG. 3, an example of an object shown on display device 50 via a three dimensional perspective view is illustrated. The display device 50 shows a displayed object 60 which preferably has a three dimensional shape. A plurality of network devices 62, 64, 66 are each represented by different regions on the surface of the displayed object 60. In addition, relationships between network devices may be shown on the displayed object 60, such as by having higher level network devices 61 displayed on an inner region of the displayed object 60. Although the displayed object 60 is shown to be stationary, it is contemplated that the displayed object may be rotated in any direction by command of an operator such that the operator may view the entire surface of the displayed object 60. In this manner, a greater number of network devices and their associated relationships with other network devices may be quickly seen at a high level. In addition to showing each network device, information associated with each network device may be displayed on the surface of the displayed object 60. For example, a status indicator of each network device may be shown via a different color on the surface region for each respective network device. For example, an out of service network device may be shown in red, an in service device may be shown in blue, and a device that has not been provisioned may be shown in green. Another method of displaying information regarding each network device would be to use a flashing indicator to display alarm conditions.

Referring to FIG. 4, a particular exemplary displayed object for a cellular communication system is illustrated. The displayed object 60 has a spherical shape, only a cross sectional slice of the sphere is shown in FIG. 4, and includes a plurality of network devices, which in this particular case are transceivers, on the outside surface of the object 60. On the inner surface, which is conical in this particular example, a plurality of higher level hierarchical related network devices associated with the transceivers at the surface are shown. For example, in the cellular communication system, the OMC 20 is a high level network device and is positioned in the core of the conical area 62. Other network devices in the system 10 are positioned above OMC 20 in a concentric fashion. For example, other network devices include mobility managers labeled MM, transcoders labeled XC, which are typically found within CBSC 14, a front end processor (FEP), a multiple span line interface processor (MSIP), a BTS link, such as the link between BTS 16 and CBSC 14, and a master group line interface (MGLI).

All of the transceivers which would be found in a particular BTS 16 are preferably arranged in a vertical segment that extends along a longitudinal line over the surface of the displayed object 60. In this manner, an operator may immediately know which transceivers are associated with a particular BTS 16. Where the displayed device 50 is a conventional resolution display, such as a CRT, it is contemplated that up to 750 transceivers may be illustrated. However, it is preferred to use a high resolution display, such as a 1280 by 1024 pixel display, so that several thousand transceivers may be viewed. In addition to the display of status information, the display system allows an operator to select one or more of the displayed network target devices, such as a particular transceiver, by clicking on the surface area associated with that transceiver, such as by using a computer mouse. After a specific target network device has been selected, many data base type operations may be performed, such as adding a new device, editing perameters on the device, activating a device, or deleting a particular device. The necessary perameters for the selected device may be provided either through keyboard data entry or through selection via a mouse.

To provide the user with further comprehension of the system, a plurality of hot link accesses from a particular network device to related information of the particular device, such as a detailed diagram or photograph of the device, may be provided. The detailed diagram or photograph may be supplemented by exploded diagrams of the device and how that device interconnects as well as a textual explanation of the purpose and capacity of each such device. Another feature provided by the display, is that a database query may be made of the system to show all network devices that possess certain qualities. For example, all devices that satisfy a particular query, such as all active devices on a particular base station 16 or connected to a particular CBSC 14, may appear in a designated color. This feature may be particularly useful in detecting defects in a network device such as a transceiver, before it fails completely. Another anticipated feature of the display device 50 and the system processor 40, is that requested additions or deletions made by the operator may be synthesized into a parts list such as an order form for new equipment. By using the display device 50 and operator commands to form a price list, rapid quotes may be made available to the customer. Although many display devices may be used, it is preferred that the device should be suited to three dimensional monitoring. An example of a suitable display device is a high speed graphics workstation, such as those made by Silicon Graphics, Inc.

Although FIG. 4 refers to the network devices of communication system 10 which is a cellular communication system, the present invention is applicable to many noncellular applications. For example, other communication network such as telephone networks, data networks or satellite networks may advantageously use the method and apparatus discussed above. In addition other systems such as utilities, transportation networks and assembly line or manufacturing environments could make use of displays such as those described herein.

The illustrative method and apparatus described herein have many advantages. For example, the apparatus provides the ability for a technical operator to quickly observe and monitor the status of any one of many, components, such as transceivers and associated elements in a complex system. Consequently, the operator may more quickly detect and react to trouble spots in the system. In addition, system operators may more quickly gain familiarity with the system due to the three dimensional user friendly presentation of system components.

Further advantages and modifications of the above described apparatus and method will readily occur to those skilled in the art. The invention, in its broader aspects, is therefore not limited to the specific details, representative

apparatus, and illustrative examples shown and described above. Various modifications and variations can be made to the above specification without departing from the scope or spirit of the present invention, and it is intended that the present invention cover all such modifications and variations provided they come within the scope of the following claims and their equivalents.

What is claimed is:

1. A method of displaying hierarchical data comprising the steps of:

retrieving hierarchical network data representative of a status of a network, said data including a plurality of data elements, each data element associated with a network device; and

displaying the hierarchical network data onto a surface of a three dimensional structure, displayed on a two-dimensional display for the purpose of controlling the network based on the display.

2. The method of claim 1, wherein said structure comprises a conical object.

3. The method of claim 1, wherein said structure is selected from the group consisting essentially of spherical objects and concentric circular objects.

4. The method of claim 1, wherein said structure changes position over a period of time.

5. The method of claim 4, wherein said structure changes position in a tumbling pattern over said period of time.

6. The method of claim 1, wherein said surface has a plurality of display regions, at least some of said display regions representing at least some of the data elements.

7. The method of claim 6, wherein at least one of said plurality of display regions is uniquely selectable.

8. The method of claim 7, wherein further information is associated with the network device linked to the data element represented by said at least one display region when said at least one display region is selected.

9. An apparatus for displaying hierarchical data comprising:

a display device;

a memory device storing the hierarchical data representative of a status of a network, said hierarchical data including a plurality of data elements, each data element associated with a network device; and

a processor responsive to said memory and including a graphical display module that displays the hierarchical network data onto a surface of a three dimensional structure, displayed on a two-dimensional display device, for the purpose of controlling the network based on the display.

10. The apparatus of claim 9, wherein said network device comprises a communication system network device.

11. The apparatus of claim 9, wherein said structure comprises one of a conical object and a spherical object.

12. The apparatus of claim 9, wherein said structure position on the display device over a period of time.

13. The apparatus of claim 9, wherein said surface has a plurality of display regions, at least some of said display regions representing at least some of the data elements.

14. The apparatus of claim 13, further comprising a pointing device in communication with said display device, and wherein at least one of said plurality of display regions is uniquely selectable by said pointing device.

15. The apparatus of claims 9, wherein said memory device comprises a first memory area storing status data associated with each network device and a second memory area storing network device relationship data defining a relationship between the data elements.

* * * * *

US006504535B1

(12) United States Patent
Edmark

(10) Patent No.: US 6,504,535 B1
(45) Date of Patent: Jan. 7, 2003

(54) DISPLAY TECHNIQUES FOR THREE-DIMENSIONAL VIRTUAL REALITY

(75) Inventor: John T. Edmark, New York, NY (US)

(73) Assignee: Lucent Technologies Inc., Murray Hill, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: 09/191,012

(22) Filed: Nov. 12, 1998

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/160,758, filed on Sep. 25, 1998, which is a continuation-in-part of application No. 09/107,059, filed on Jun. 30, 1998.

(51) Int. Cl.[7] G06T 15/00
(52) U.S. Cl. 345/419; 345/427; 345/428; 345/629; 345/632
(58) Field of Search 345/132, 427, 345/428, 419, 423, 426, 473, 629, 632, 634, 638, 639, 640, 641, 646, 647

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Primary Examiner—Mark Zimmerman
Assistant Examiner—Enrique L Santiago
(74) *Attorney, Agent, or Firm*—John G. De La Rosa

(57) **ABSTRACT**

A limitation of using two-dimensional images, such as videos or photographs, to represent portions of a three-dimensional world occurs when the user moves within the world and views the world from a location different than from the original context of the two-dimensional image, i.e., from a location different than the image's ideal viewing point (IVP). View changes result in the image not aligning well with the surrounding objects of the three-dimensional world. This limitation is overcome by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a pyramidic panel structure. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and its surroundings. To minimize the depth profile of the pyramidic panel structure, the structure may be segmented into sections and each section translated towards, or away from, the user's viewpoint. Also, a hierarchical image resolution may be used, with portions of the image near the center or vanishing point having a higher resolution than the portions of the image near its perimeter.

15 Claims, 14 Drawing Sheets

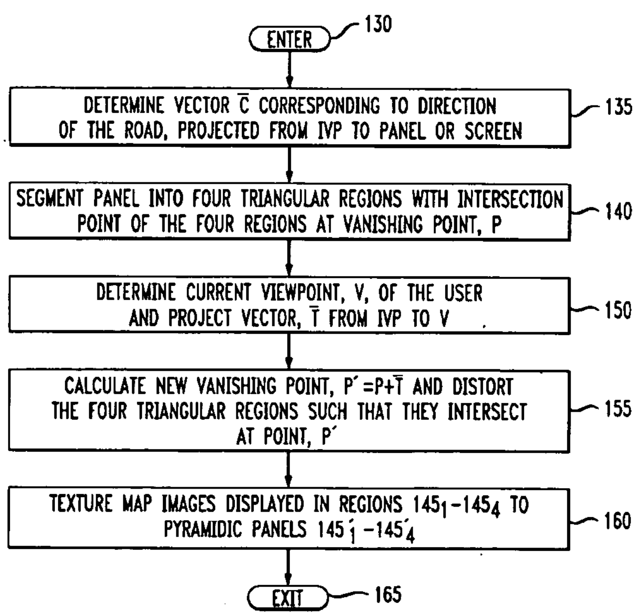


FIG. 1

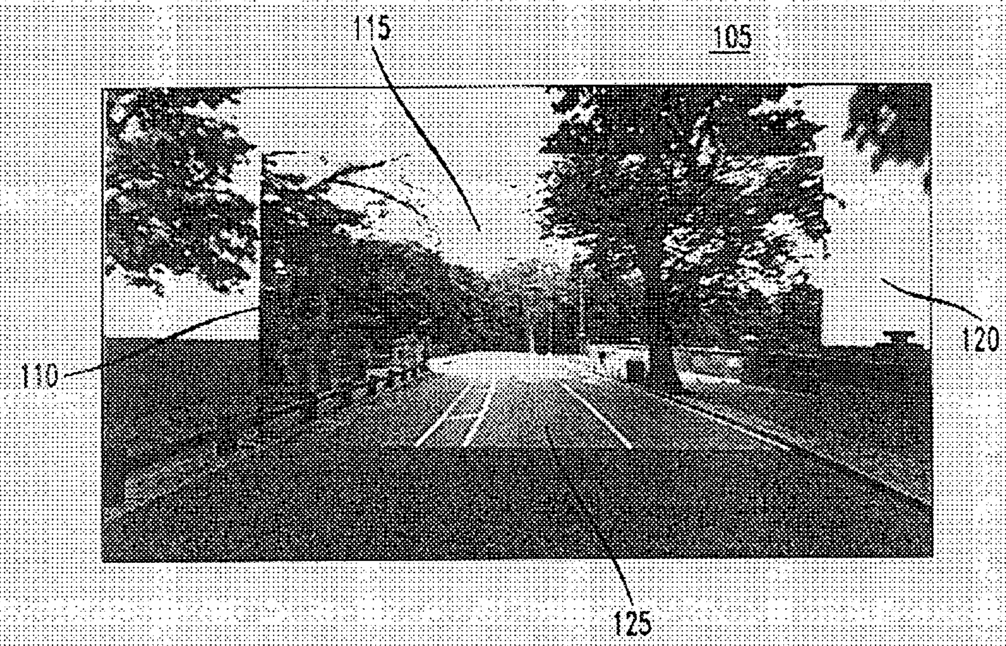


FIG. 2

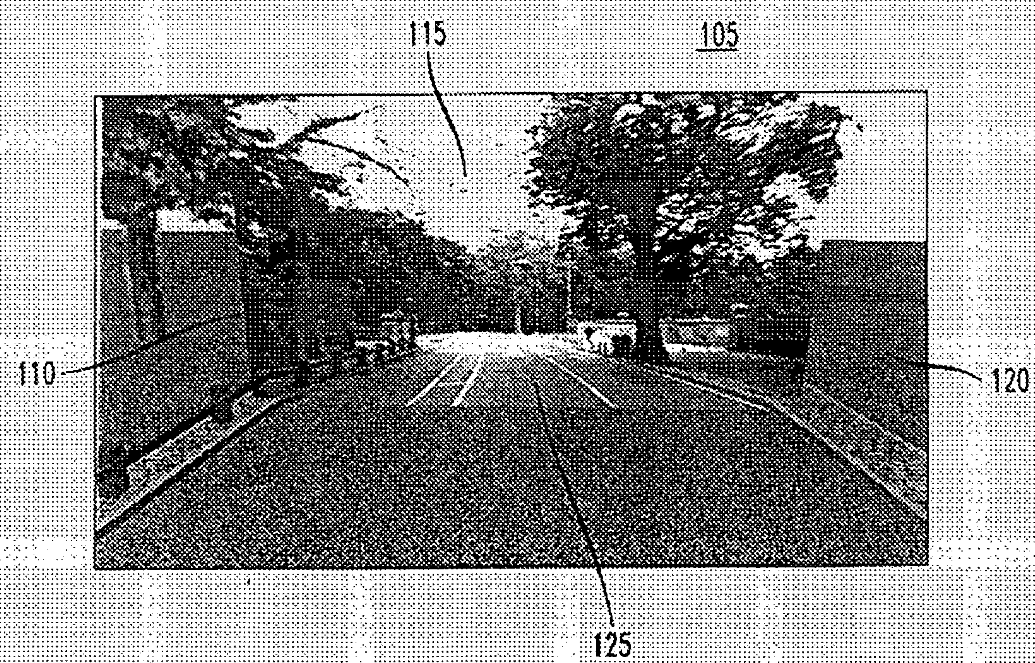


FIG. 3

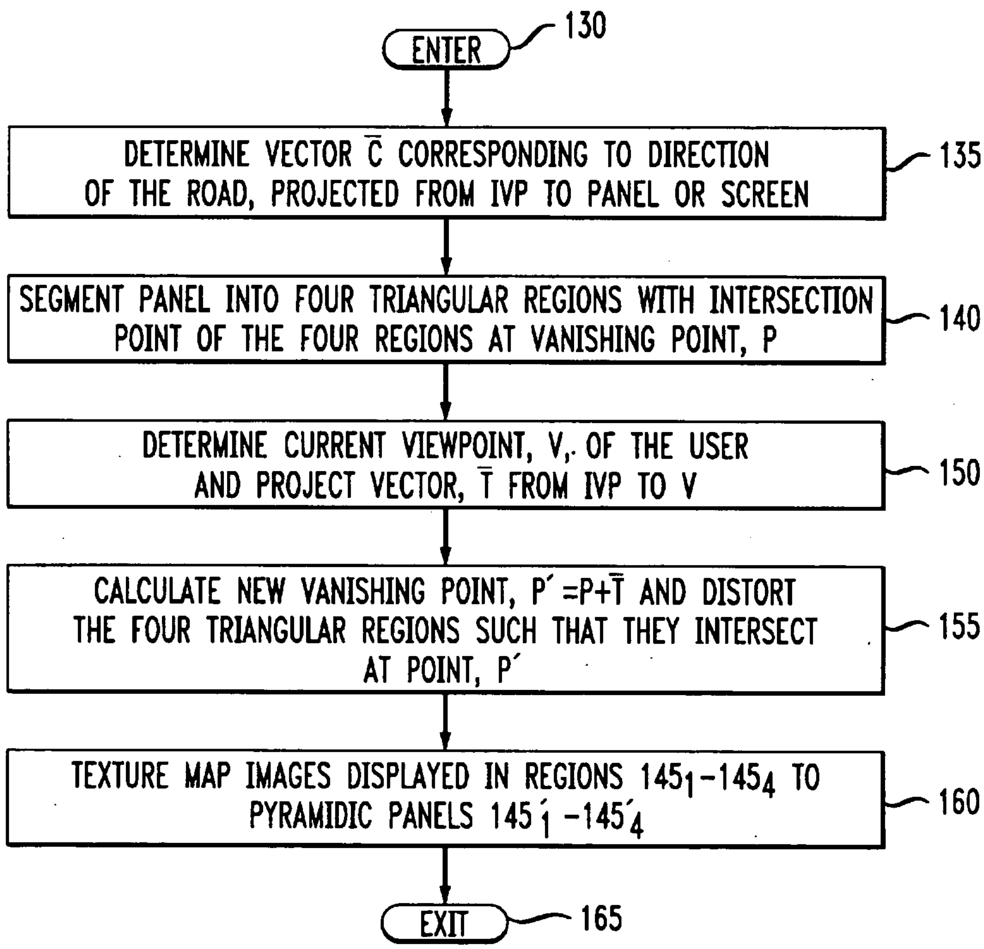

ENTER
130
DETERMINE VECTOR $\bar{C}$ CORRESPONDING TO DIRECTION OF THE ROAD, PROJECTED FROM IVP TO PANEL OR SCREEN
135
SEGMENT PANEL INTO FOUR TRIANGULAR REGIONS WITH INTERSECTION POINT OF THE FOUR REGIONS AT VANISHING POINT, P
140
DETERMINE CURRENT VIEWPOINT, V, OF THE USER AND PROJECT VECTOR, $\bar{T}$ FROM IVP TO V
150
CALCULATE NEW VANISHING POINT, $P' = P + \bar{T}$ AND DISTORT THE FOUR TRIANGULAR REGIONS SUCH THAT THEY INTERSECT AT POINT, P′
155
TEXTURE MAP IMAGES DISPLAYED IN REGIONS 145_1-145_4 TO PYRAMIDIC PANELS $145'_1$-$145'_4$
160
EXIT
165

FIG. 4

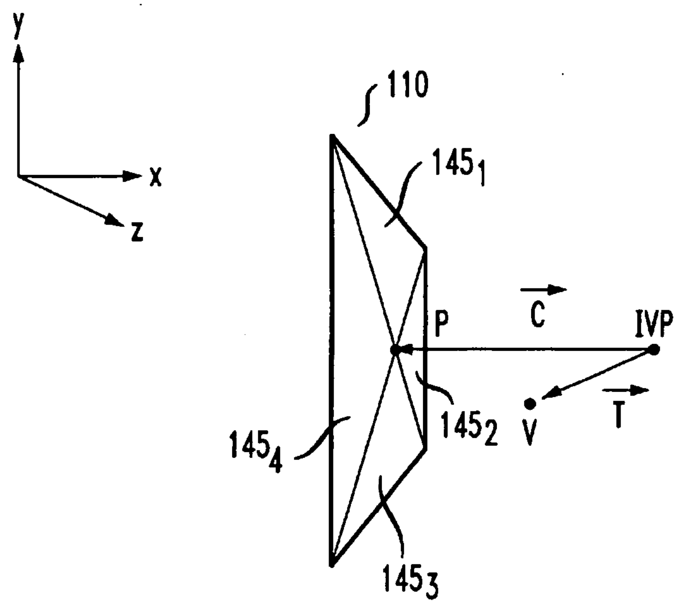

y
x
z
110
145₁
P
C
IVP
145₂
V
T
145₄
145₃

FIG. 5

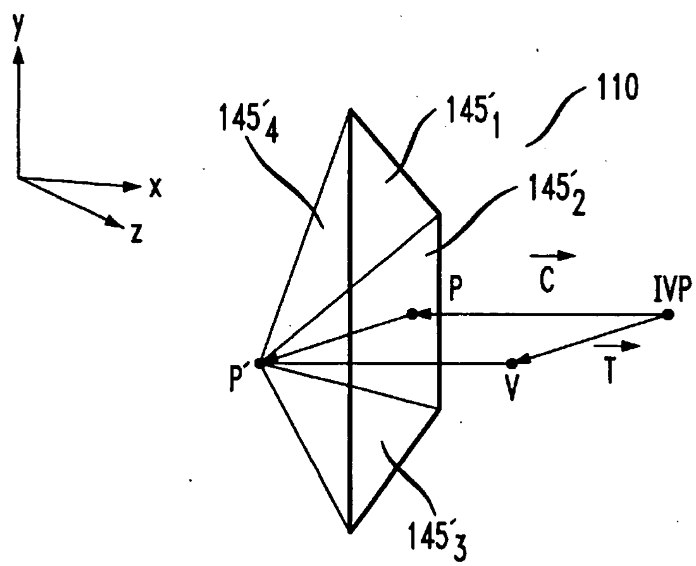

y
x
z
145'₄
145'₁
110
145'₂
P
C
IVP
P'
V
T
145'₃

FIG. 6A

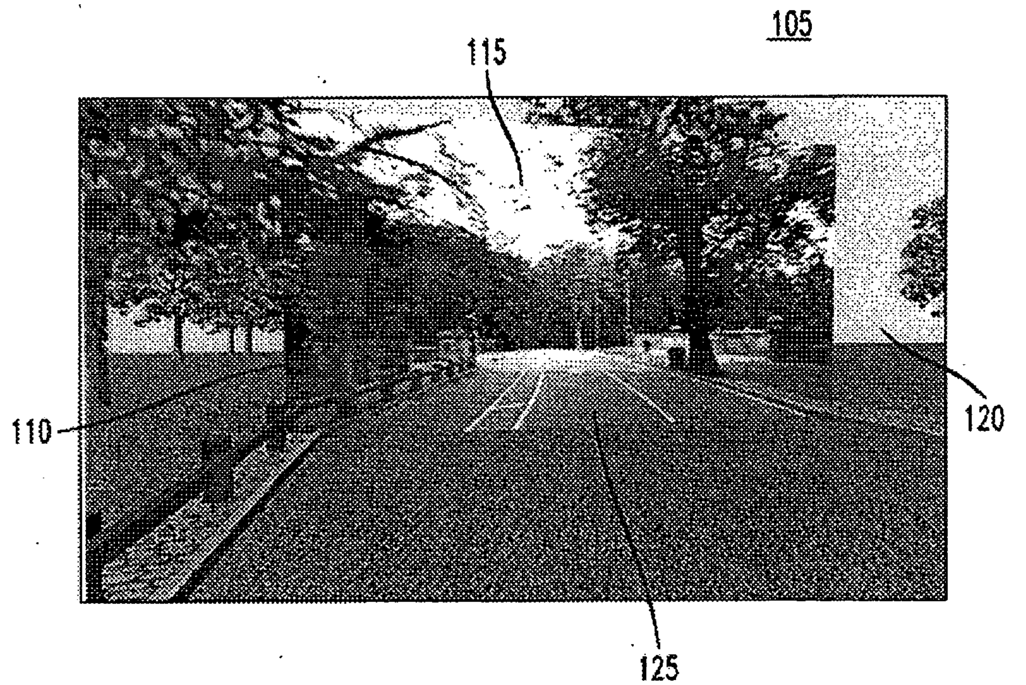


FIG. 6B

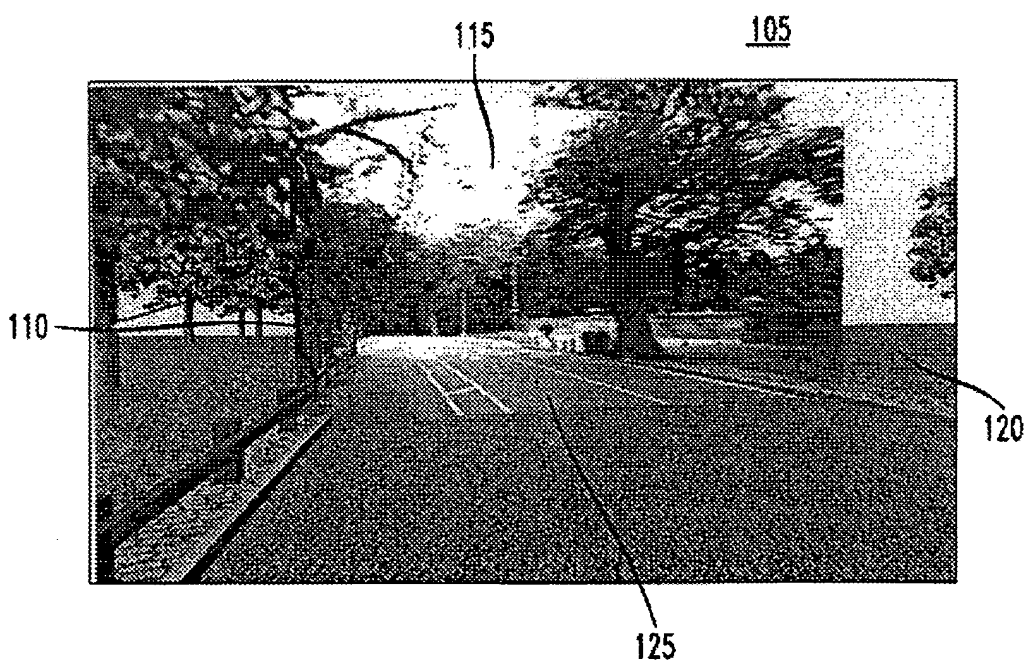


FIG. 7A

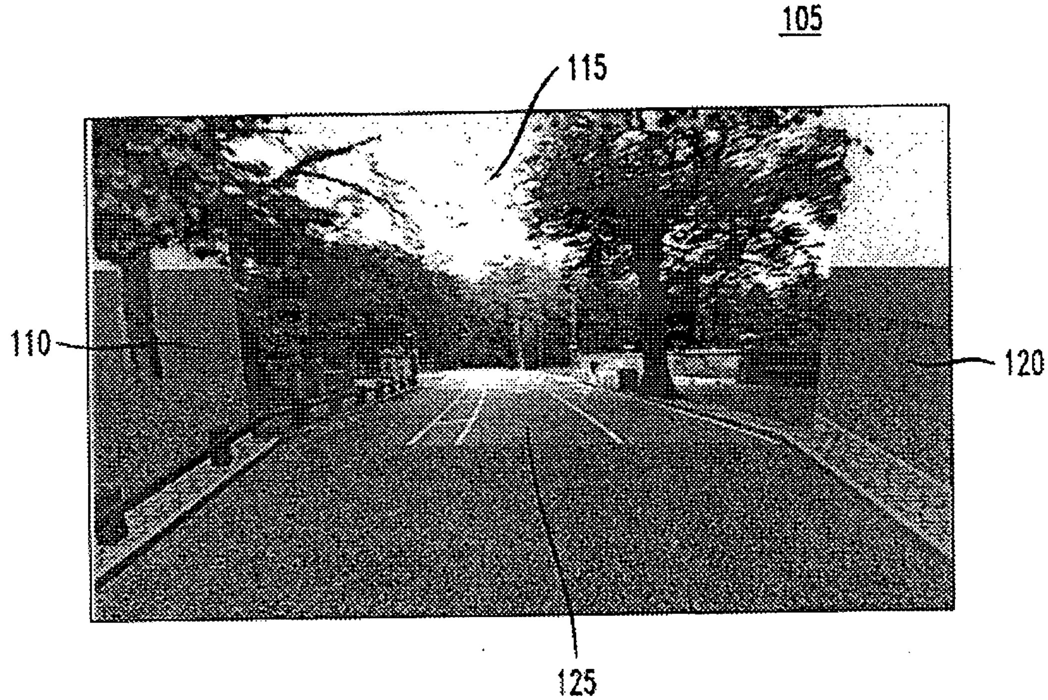


FIG. 7B

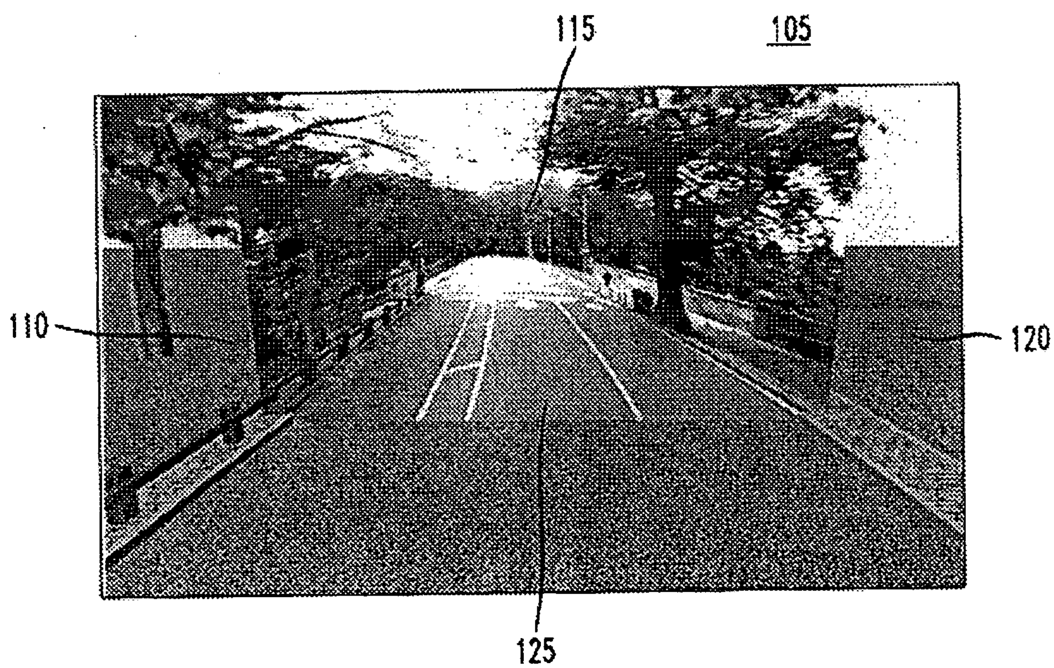


FIG. 8A

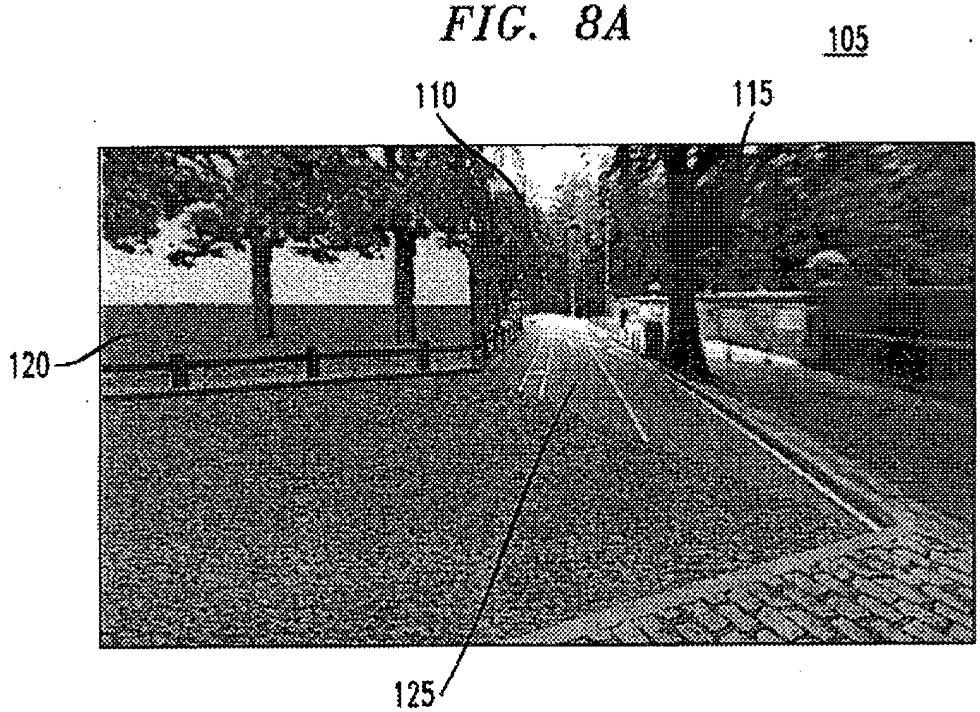


FIG. 8B

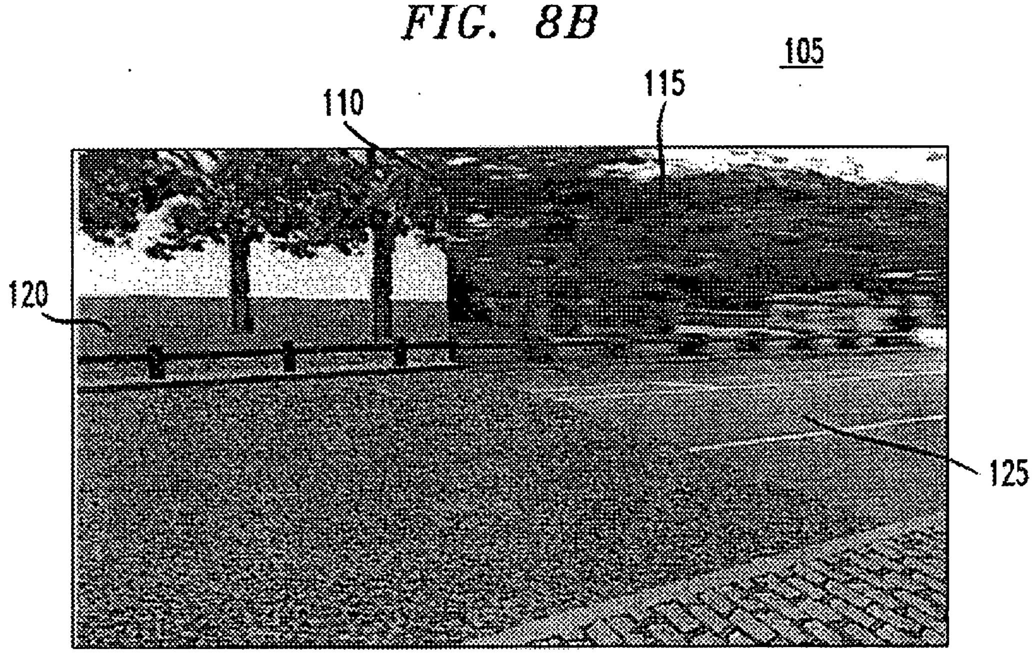


FIG. 9

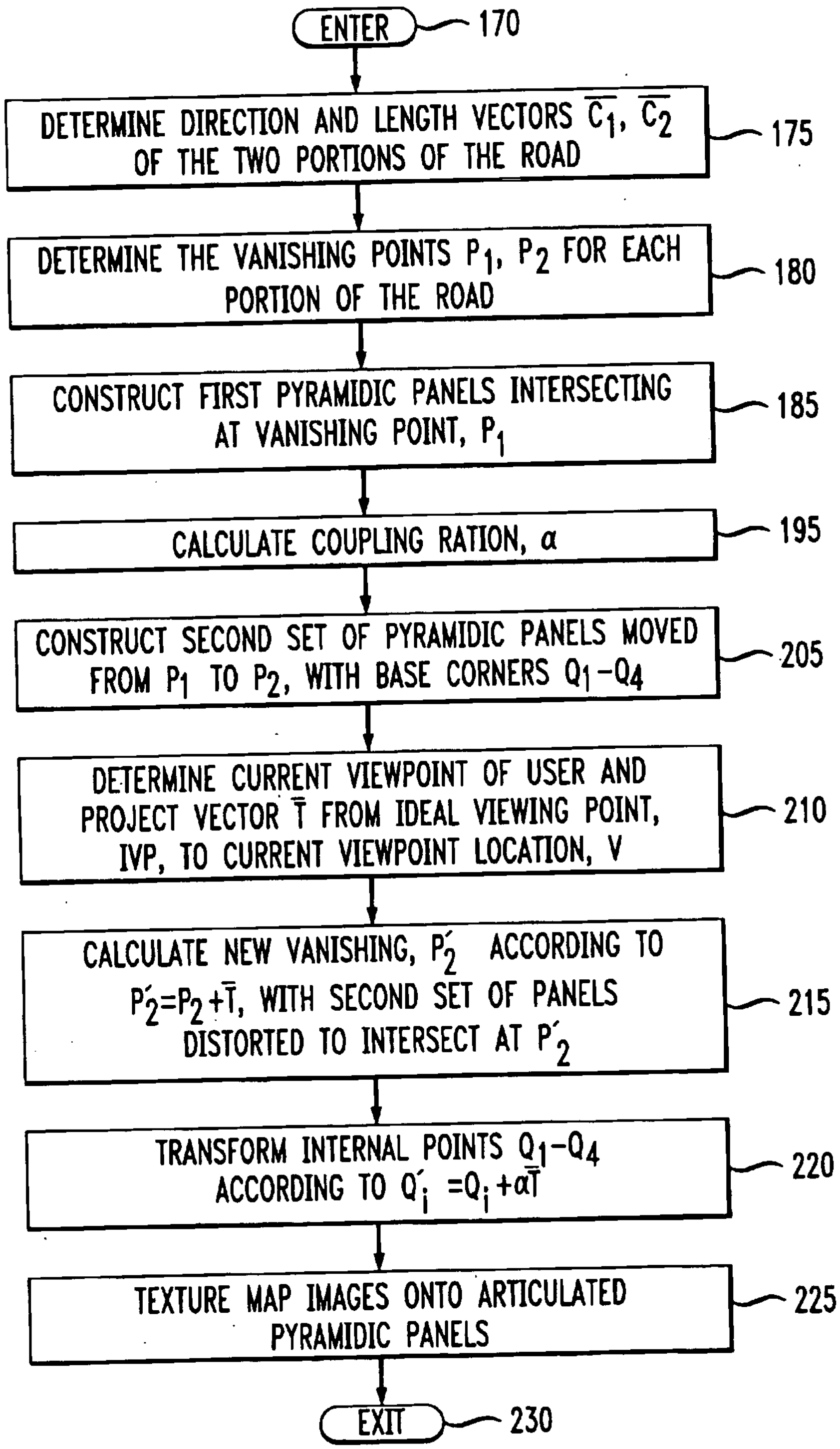

ENTER
170
DETERMINE DIRECTION AND LENGTH VECTORS $\overline{C_1}$, $\overline{C_2}$ OF THE TWO PORTIONS OF THE ROAD
175
DETERMINE THE VANISHING POINTS P_1, P_2 FOR EACH PORTION OF THE ROAD
180
CONSTRUCT FIRST PYRAMIDIC PANELS INTERSECTING AT VANISHING POINT, P_1
185
CALCULATE COUPLING RATION, α
195
CONSTRUCT SECOND SET OF PYRAMIDIC PANELS MOVED FROM P_1 TO P_2, WITH BASE CORNERS Q_1–Q_4
205
DETERMINE CURRENT VIEWPOINT OF USER AND PROJECT VECTOR $\overline{T}$ FROM IDEAL VIEWING POINT, IVP, TO CURRENT VIEWPOINT LOCATION, V
210
CALCULATE NEW VANISHING, P_2' ACCORDING TO $P_2'=P_2+\overline{T}$, WITH SECOND SET OF PANELS DISTORTED TO INTERSECT AT P_2'
215
TRANSFORM INTERNAL POINTS Q_1–Q_4 ACCORDING TO $Q_i' = Q_i+\alpha\overline{T}$
220
TEXTURE MAP IMAGES ONTO ARTICULATED PYRAMIDIC PANELS
225
EXIT
230

FIG. 10

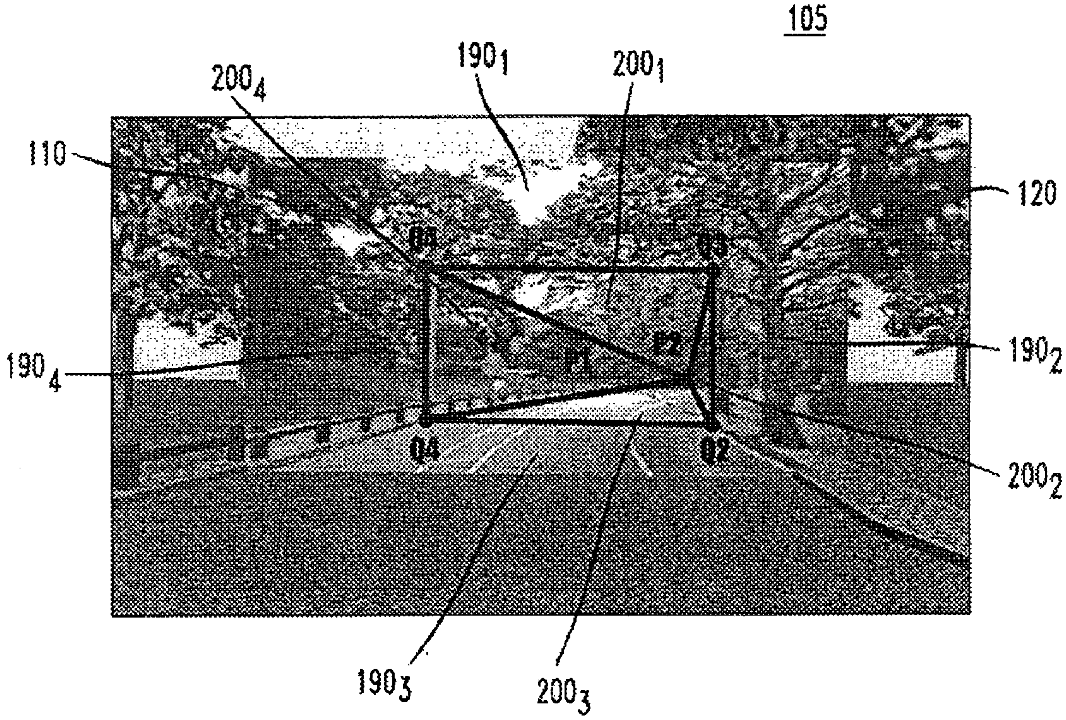

105
190_1
200_1
200_4
110
120
Q5
Q3
P1
P2
190_4
190_2
Q4
Q2
200_2
190_3
200_3

FIG. 11

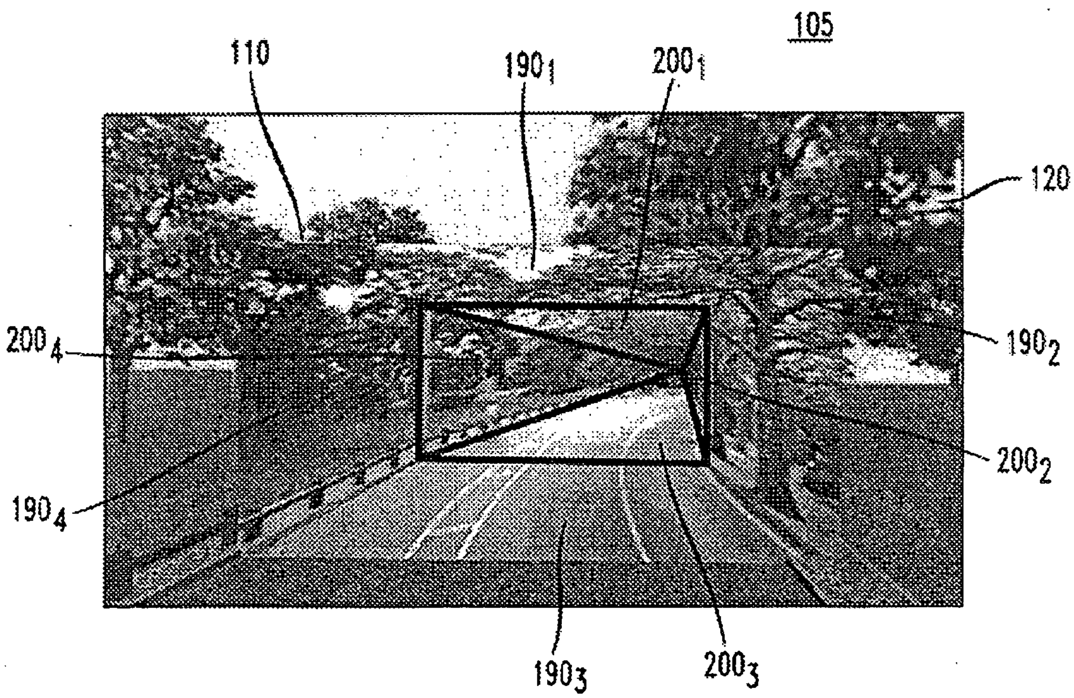
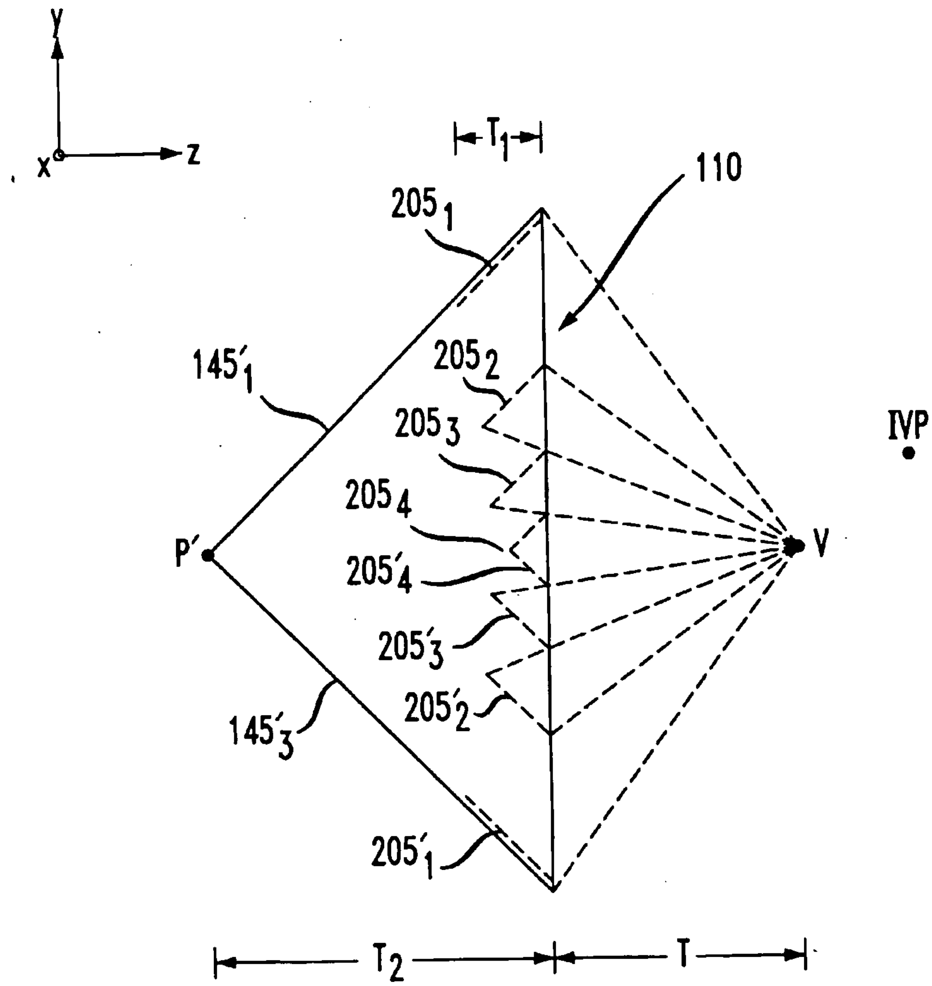

105
110
190_1
200_1
120
200_4
190_2
200_2
190_4
190_3
200_3

FIG. 12



y
x
z
T1
110
2051
1451'
2052
2053
IVP
2054
P'
V
2054'
2053'
2052'
1453'
2051'
T2
T

FIG. 13

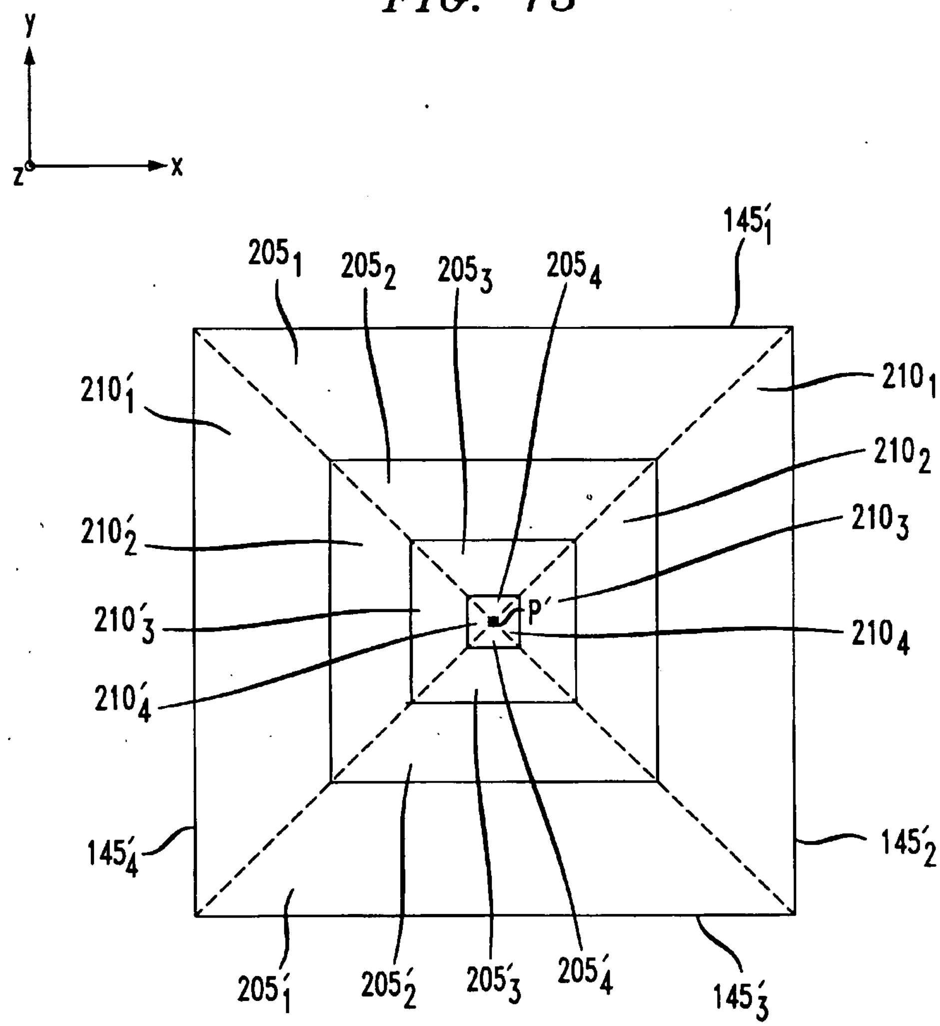

y
x
z
$145'_1$
205_1
205_2
205_3
205_4
$210'_1$
210_1
210_2
$210'_2$
210_3
P'
$210'_3$
210_4
$210'_4$
$145'_4$
$145'_2$
$205'_1$
$205'_2$
$205'_3$
$205'_4$
$145'_3$

FIG. 14

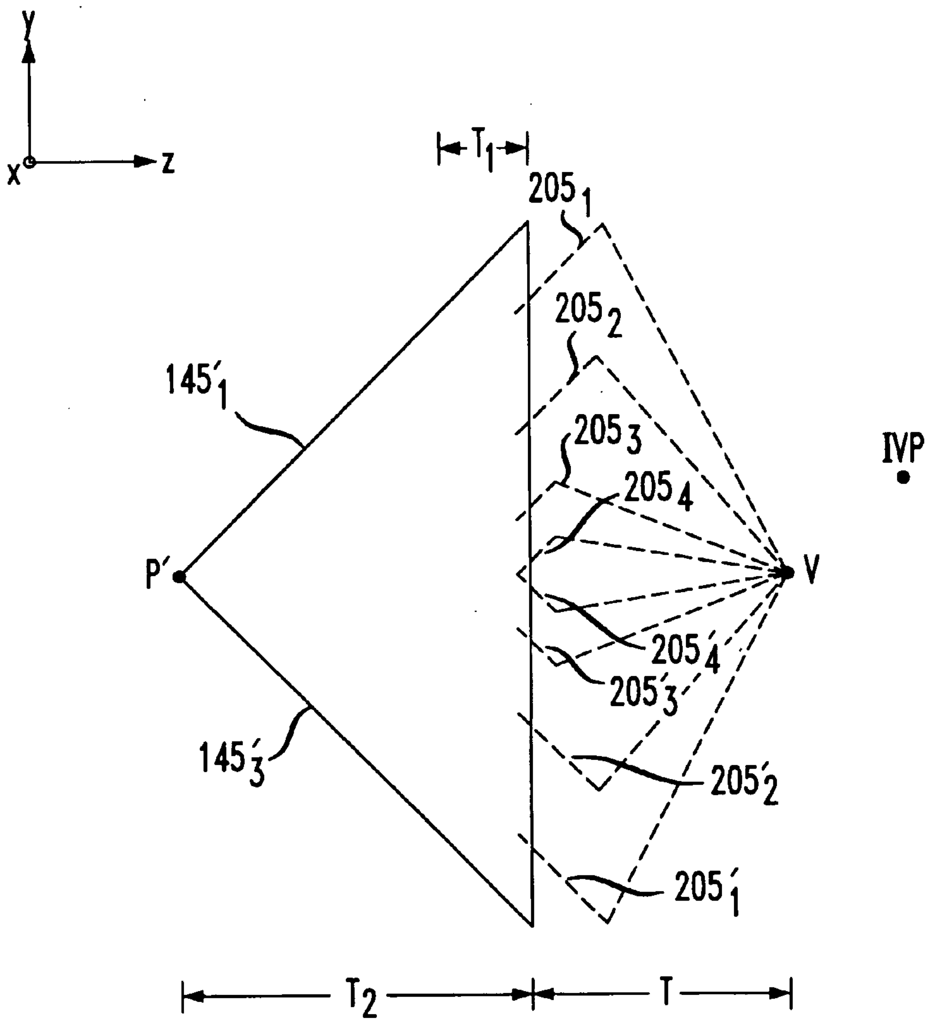

y
x
z
T_1
205_1
205_2
205_3
205_4
$145'_1$
P'
V
IVP
$205'_4$
$205'_3$
$145'_3$
$205'_2$
$205'_1$
T_2
T

FIG. 15

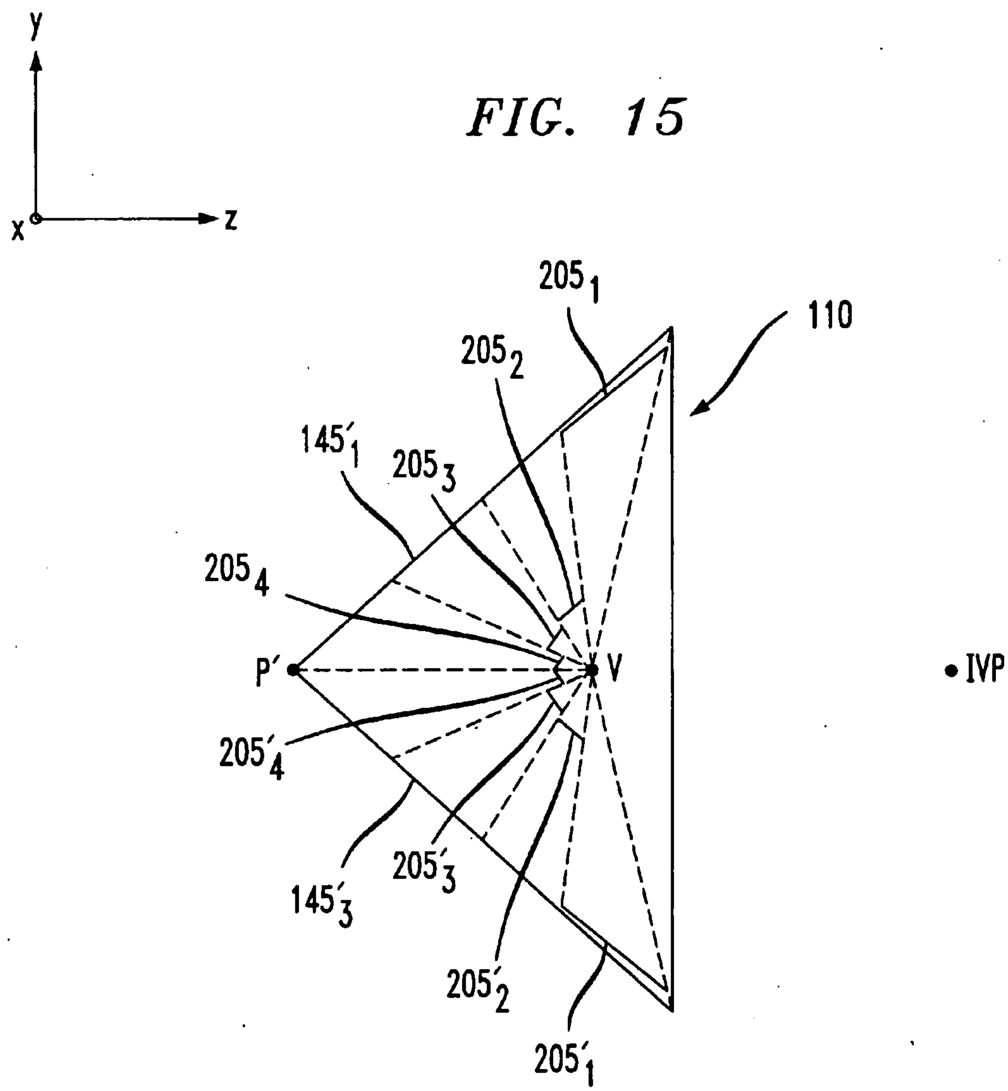

y
x
z
205_1
110
205_2
$145'_1$
205_3
205_4
P′
V
IVP
$205'_4$
$145'_3$
$205'_3$
$205'_2$
$205'_1$

FIG. 16

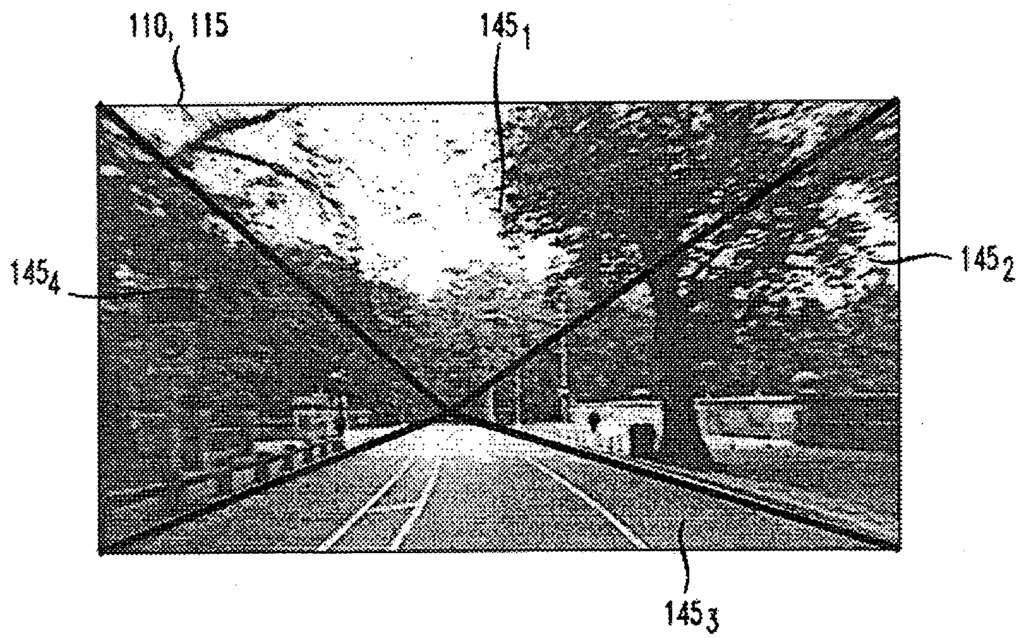


FIG. 17

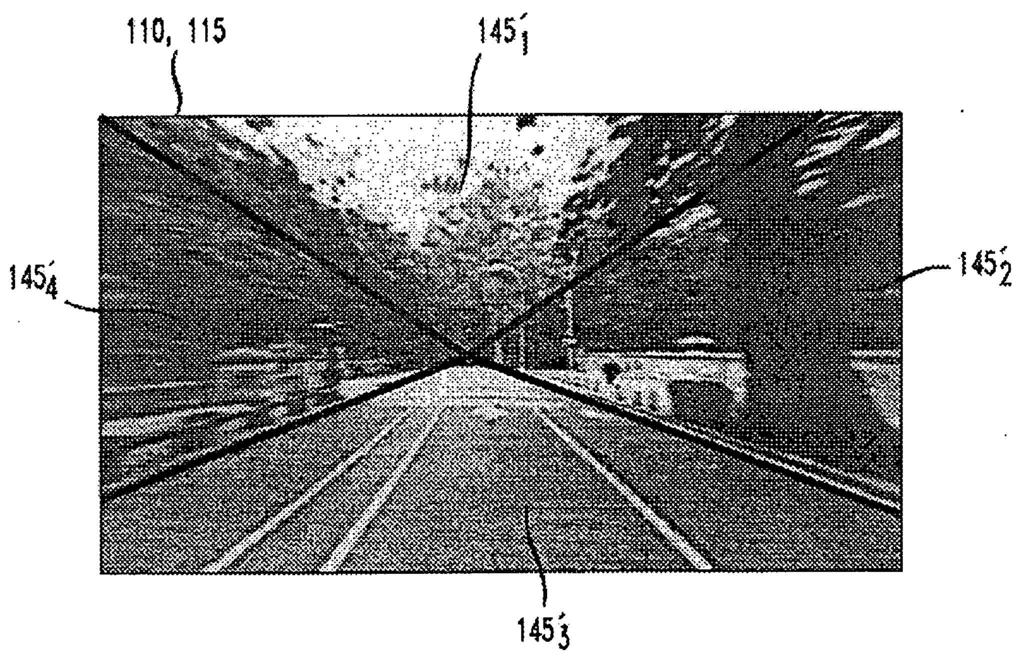
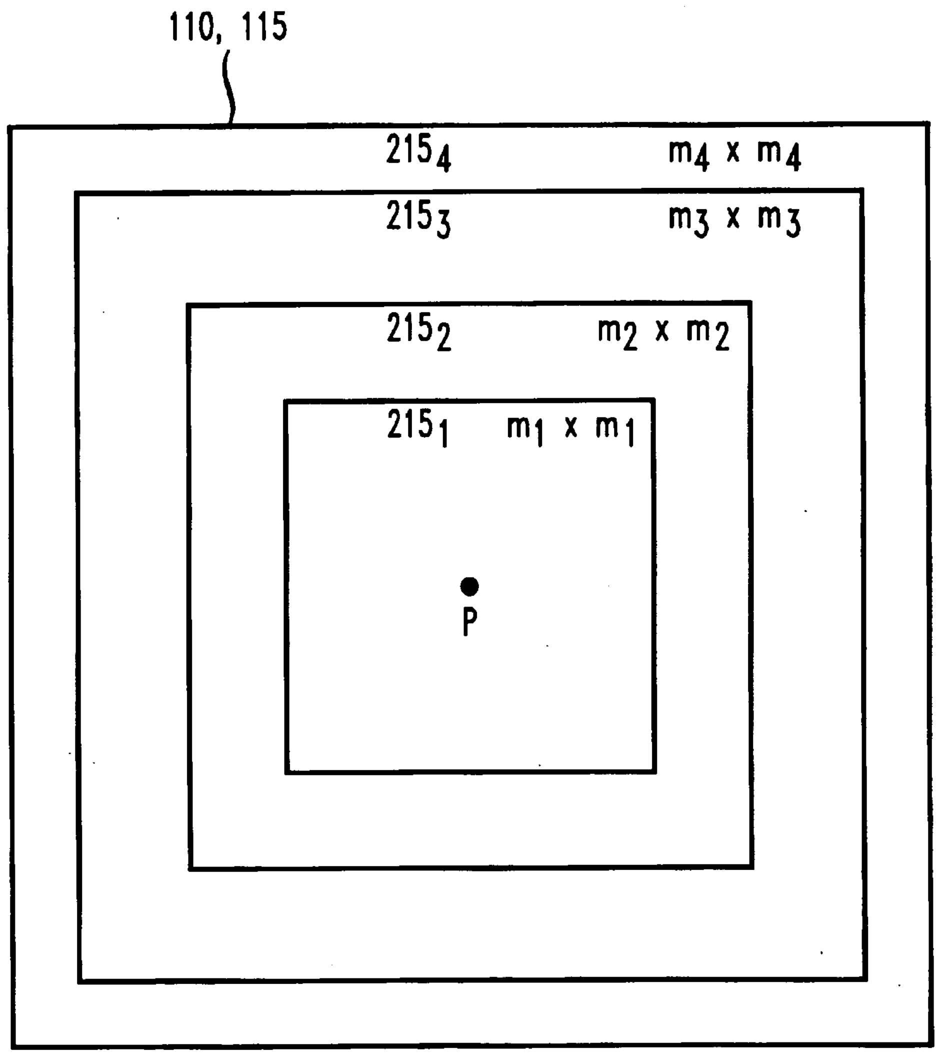


FIG. 18



DISPLAY TECHNIQUES FOR THREE-DIMENSIONAL VIRTUAL REALITY

CROSS-REFERENCE TO RELATED APPLICATION

This application is related to co-pending U.S. patent application Ser. No. 09/190,743 filed concurrently herewith (Case Edmark-7). Also, this application is a continuation-in-part of U.S. patent application Ser. No. 09/160,758 filed Sep. 25, 1998 (Case Edmark-5), which is a continuation-in-part of U.S. patent application Ser. No. 09/107,059 filed Jun. 30, 1998 (Case Edmark-2). The above-identified co-pending applications, which are commonly assigned, are incorporated herein by reference.

TECHNICAL FIELD

This invention relates to the integration of three-dimensional computer graphics and a two-dimensional image to provide a realistic three-dimensional virtual reality experience.

BACKGROUND OF THE INVENTION

The display of a three-dimensional virtual reality world to a user requires considerable computation power, and it is typically costly to develop the necessary highly detailed models required for doing so. In order to simplify the problem, two-dimensional images, such as videos or photographs, may be used to represent or simulate portions of the three-dimensional world. A great reduction in computation power and cost can be achieved by such an arrangement.

SUMMARY OF THE INVENTION

A limitation of such a world occurs when a user moves within the world and views the world from a location different than the original context of a two-dimensional image which has been carefully calibrated to "fit into" the world. View changes, such as from a location different than the image's ideal viewing point, result in the image not aligning or fitting well with the surrounding objects of the three-dimensional world. I have recognized that, in accordance with the principles of the invention, viewpoint changes may be dealt with by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a novel "pyramidic panel structure." In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and the surroundings of the world.

In another aspect of the present invention, the pyramidic panel structure may be segmented into sections, each translated towards or away from the user's viewpoint and then scaled, so as to minimize the depth profile of the pyramidic panel structure. In yet still another aspect of the present invention, a hierarchical image resolution may be used, with portions of the image near the center of the image having a higher resolution than the portions of the image near its perimeter.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 shows an example of that which a user sees when a user views the world from the ideal viewing point for a two-dimensional image representing a portion of the world;

FIG. 2 shows an example of that which a user sees when a user moves within the world of FIG. 1 and views the two-dimensional image from a location different than the image's ideal viewing point, without the use of the present invention;

FIG. 3 shows an exemplary process, in accordance with the principles of the invention, for distorting the two-dimensional image using a pyramidic panel structure so as to adjust the image's vanishing point in accordance with the movement of the user;

FIGS. 4 and 5 depict the pyramidic panel structure of the present invention for distorting the two-dimensional image so as to adjust the image's vanishing point, in accordance with the movement of the user;

FIGS. 6A–B depict examples of that which a user sees when a user views the world from a location left of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 7A–B depict examples of that which a user sees when a user views the world from a location above the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 8A–B depict examples of that which a user sees when a user views the world from a location toward the front and the right of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIG. 9 shows an exemplary process, in accordance with the principles of the invention, for distorting a two-dimensional image using an articulated pyramidic panel structure so as to adjust multiple vanishing points in the image, in accordance with the movement of the user;

FIG. 10 depicts an example of the articulated pyramidic panel structure of the present invention;

FIG. 11 depicts an example of that which a user sees when a user views the world from a location away from the ideal viewing point of the two-dimensional image, with the use of the articulated pyramidic panel structure of the present invention;

FIGS. 12 and 13 depict side and front views, respectively, of the pyramidic panel structure of FIG. 5 with each panel segmented into a plurality of sections;

FIG. 14 depicts the pyramidic panel structure of FIG. 5, with each panel segmented into a plurality of sections having its centers located on the surface of a predetermined plane;

FIG. 15 depicts the pyramidic panel structure of FIG. 5, with each panel segmented into a plurality of sections and each section translated a different distance toward the user's view point, V;

FIG. 16 depicts the screen of the pyramidic panel structure of the present invention segmented into four triangular sections with the corresponding portions of a two-dimensional image displayed in each panel;

FIG. 17 depicts the screen of FIG. 16 from a location closer to the center of the image, with the corresponding portions of the image textured-mapped onto the pyramidic panels in accordance with the present invention; and

FIG. 18 depicts the screen of FIG. 16 with the two-dimensional image segmented into a plurality of sections in accordance with another aspect of the present invention.

DETAILED DESCRIPTION

To better understand the invention, FIGS. 1–2 show examples of that which user sees when the user moves

within a three-dimensional virtual reality world (x,y,z) and views a two-dimensional image (x,y) representing a portion of the world from a location at the image's ideal viewing point (IVP), and then from a different location, i.e., a location different than the original context of the image. It should be understood that the two-dimensional image has been carefully calibrated to "fit into" the surroundings of the world. For simplification of terminology purposes, we shall use the term two-dimensional image to denote either a video clip or a photograph. In accordance with the principles of the invention, as the user moves away from the ideal viewing point, discontinuities between the two-dimensional image and its surroundings are minimized by distorting the image according to the movement of the user.

FIG. 1 shows an exemplary three-dimensional reality world **105**, which is a bicycle path in a park, e.g., Central Park in New York City. In representing world **105**, the present invention exploits a characteristic common for images consisting of views looking down the center of roads, streets or paths, which is that they may be treated as perspective, corridor-like images, with features closer to the center of the image being farther away from the viewer along the z-axis. Accordingly, the bicycle path or road and its immediate vicinity are treated as a kind of three-dimensional, corridor-like image whose floor is formed by the roadbed, whose ceiling is formed by the sky, and whose sidewalls are formed by the roadside objects. In this manner, the principles of a simple point perspective can be used for distorting the landscape image in accordance with the movement of the viewer, as discussed herein below.

World **105** is divided into two portions, screen or panel **110** on which is shown or displayed a two-dimensional image **115**, such as a still photograph, picture, or a current frame of a video clip; and the remainder of the world **120**, which is represented using computer graphics techniques, and is thus referred to herein as computer graphics (CG Part) **120**. Within CG Part **120** there are various synthetic, three-dimensional landscapes or objects modeled in, for example, the Virtual Reality Modeling Language (VRML). Two-dimensional image **115** simulates landscape or terrain portions of the world **105**, here a virtual road or course **125** for walking, running or pedaling a bicycle.

Note that although three-dimensional world **105** cannot be actually rendered in a two-dimensional plane (x,y), it can be projected to and displayed on a two-dimensional plane so as to appear to have three dimensions (x,y,z). Accordingly, the techniques of the present invention are preferably employed with computers and software, which are sufficiently sophisticated to display images on a two-dimensional plane as having three dimensions. Note also that to make the world look realistic, computer graphics display techniques use the z component of objects to scale accordingly the x and y components as a function of its distance (z-axis) to the user's viewpoint.

Two-dimensional image **115** is carefully placed, cropped and sized to achieve continuity with the surrounding environment of the CG Part **120**. Note that the image is clipped so that the left and right edges of the road in CG Part **120** pass through the left and right bottom comers of the road, respectively, in image **115**. This clipping ensures that the roadbed maps to the floor of the hypothetical corridor. In so doing, portions at the boundary between two-dimensional image **115** and CG part **120** are co-planar, i.e., at the same distance away along the z-axis from the user's viewpoint. In "fitting" two-dimensional image **115** to CG part **120**, however, there exits only one viewpoint from which that image's content properly corresponds to the surrounding environment of CG Part **120**. This unique location is called the image's ideal viewing point (IVP). In FIG. **1**, two-dimensional image **115** is seen from its ideal viewing point, and from this view, image **115** aligns well with the surrounding objects of CG Part **120**.

Users, however, rarely view image **115** only from its idea viewing point. As the user moves within world **105**, such as left or right of road **125**, as they round curves, or move closer to or farther from the image, they see image **115** from positions other than its ideal viewing point. Absent the use of the present invention, such viewpoint changes would cause objects or features within image **115** to align improperly with the surrounding environment, as further illustrated in FIG. **2**.

In accordance with the principles of the invention, however, screen or panel **110** uses a display structure called a "pyramidic panel structure" for displaying two-dimensional image **115** within the surrounding three-dimensional space of the CG Part **105** so as to deal with viewpoint changes. The transformations associated with the pyramidic panel structure dynamically distort two-dimensional image **115** according to viewer's position so as to adjust the image's vanishing point with the viewer's movement. As the viewer moves from the image's ideal viewing point, these distortions act to limit discontinuities between image **115** and the surroundings of CG Part **120**.

FIG. **3** shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image **115** so as to adjust its vanishing point in accordance with the viewer's position. The process is entered at step **130** whenever it is determined that the viewer's position has changed.

Using the virtual world's road model of the CG Part **105**, a vector, C, corresponding to the direction of road **125** is projected at step **135** from the image's ideal viewing point, IVP, to panel or screen **110** on which is displayed image **115**. Note that the panel is two-dimensional, but represents three-dimensional space with objects nearer the center of the image being farther away from the plane of the viewer. The panel structure is shown in FIG. **4**. The point of intersection with screen or panel **110** is the image's vanishing point, P. Note, however, that the vanishing point may be set visually by the user, if desired, or by other suitable computer graphics processing techniques known in the art. Next, in step **140**, screen or panel **110** is segmented into four triangular regions 145_{1-4}, one for each of the regions bordering CG Part **120**, with the intersection point of the four regions located at the vanishing point, P.

Thereafter in step **150**, the current viewpoint of the user, V, is determined, and a vector $\overline{T}$ projected from the ideal viewing point, IVP, to the viewer's current location, V. In accordance with the principles of the invention, as the viewer moves, a new vanishing point P' is calculated as $P'=P+\overline{T}$. The four triangular regions 145_{1-4} are distorted in the three-dimensional space of the virtual world at step **155** to represent the mapping of objects nearer the center of the image being displaced farther away from the viewpoint of the user. The four triangular regions intersect at the new vanishing point P' and form so-called "pyramidic panels" $145'_{1-4}$. This is illustrated in FIG. **5**. At step **160**, the corresponding images displayed in regions 145_{1-4} are then "texture-mapped" onto pyramidic panels $145'_{1-4}$ respectively. In this manner, as the viewer moves away from the image's ideal viewing point, IVP, distortions in the image resulting from moving the image's vanishing point from P to P' act to limit the discontinuities between image **115** and the surroundings within CG Part **105**.

In the exemplary illustration of FIG. **5**, distorting image **115** so as to move the vanishing point from P to P' results in pyramidic panel structure forming a four-sided pyramid. Note that its base is fixed and corresponds to original screen or panel **110**, with its peak located at P', which moves in concert with the viewer's current location, V. As the user's viewpoint moves closer to and farther from the image, the image's vanishing point accordingly moves farther from and closer to the user's viewpoint, respectively.

FIGS. **6** through **8** compare the display of two-dimensional image **115** on screen or panel **110** with the display of the same image using the "pyramidic" panels of the present invention. More specifically, FIGS. **6A**, **7A** and **8A** depict viewing two-dimensional image **115** at a location from the left, above, and in front and to the right of the image's ideal viewing point, IVP, respectively, without the use of the present invention. In these latter figures, note that there are discontinuities between the edges of the road and the three-dimensional space of CG Part **105**. FIGS. **6B**, **7B** and **8C** depict the same two-dimensional image distorted and texture-mapped onto pyramidic panels $145'_{1-4}$, in accordance with the principles of the invention. Note that in these latter figures, the discontinuities in the road edge have been substantially eliminated.

In another embodiment of the present invention, a modified pyramidic panel structure may be used to deal with two-dimensional images containing curved roads, streets, paths and other corridor-like images containing multiple rather than a single vanishing point. In this latter case, screen or panel **110** is segmented using multiple vanishing points to form a so called "articulated pyramidic panel structure." The transformations associated with the articulated pyramidic panel structure dynamically distort different portions of two-dimensional image **115** according to viewer positions so as to adjust the different vanishing points of the image with the viewer's movement. Likewise, as the viewer moves from the image's ideal viewing point, these distortions act to limit the discontinuities between two-dimensional image **115** and the surroundings of CG Part **120**.

FIG. **9** shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image **115** using an articulated pyramidic panel structure. Again, the process is entered at step **170** whenever it is determined that the viewer's position has changed. In general, curve road **125** is treated as two straight corridors placed end-to-end, extending back from screen or panel **110**. Each corridor represents a different portion of road **125** in the three-dimensional space of world **105**, with features nearer the center of the image being farther away from the user's viewpoint.

Using the virtual world's road model of the CG Part **105**, corresponding directional vectors C_1 and C_2 of the corridors are determined at step **175**. Note that portion of the road nearer to the user's viewpoint is represented by C_1, and the portion farther away is represented by C_2. Next, in step **180**, using the vectors C_1 and C_2, the corresponding vanishing points P_1 and P_2 are determined, respectively, for each corridor by projecting those vectors from the image's ideal viewing point, IVP. Alternatively, vanishing points P_1 and P_2 may be determined visually by the user, or by some other suitable means known in the art. In step **185**, using the first corridor's vanishing point, P_1, a first set of pyramidic panels 190_{1-4} are constructed to intersect at vanishing point, P_1, as shown in FIG. **10**.

Now at step **195**, a coupling ratio α is calculated according to the following equation: $\alpha=l/(l+d)$, where l is the length of the first corridor, and d is the distance between the image's ideal view point (IVP) and the base of pyramidic panels 190_{1-4}. Each line segment connecting a corner of the base to vanishing point P_1 is then divided into two segments by a point placed according to the coupling ratio, α. More specifically, the length l' of each line segment from the corner of the base of panels 190_{1-4} to this point is given by $l'=\alpha l''$, where l" is the total length of the segment between the corner of the panel and the vanishing point, P_1. These four points labeled Q1 through Q4 are connected to form the base of a second set of smaller pyramidic panels 200_{1-4} embedded within the larger panels (step **205**), as further illustrated in FIG. **10**. The intersection point of pyramidic panels 200_{1-4} is then moved from P_1 to vanishing point, P_2.

For the articulated pyramidic panel structure, the current viewpoint of the user, V, is determined, and a vector **T** projected from the ideal viewing point, IVP, to the viewer's current location, V (step **210**). As the viewer moves, a new vanishing point P_2' is calculated as $P_2'=P_2+\overline{T}$ at step **215**, and panels 200_{1-4} are then distorted so as to intersect at P_2'. As the viewer move, the four internal points Q1 through Q4 are mapped with the viewer's movement to Q1' through Q4', respectively, in accordance with the following relationship: $Q_i'=Q_i+\alpha\overline{T}$, at step **220**. Note that doing so, accordingly distorts the first set of pyramidic panels 190_{1-4}. At step **225**, the corresponding images in original panels are then texture-mapped into articulated pyramidic panels 190_{1-4} and 200_{1-4}, which have been distorted in accordance with the movement of the viewer. Note that to unambiguously texture-map onto panels 190_{1-4}, these panels are each subdivided into two triangular subregions and then texture-mapped. Shown in FIG. **11** is image **115** seen from a location away from the image's ideal viewing point, using the articulated pyramidic panel structure of the present invention.

Note that the above articulated pyramidic panel structure may also use more than two sets of pyramidic panel structures. Instead of treating the curve road as two straight corridors, multiple corridors may be employed, each placed end-to-end and extending back from screen or panel **110**. Likewise, each corridor represents a different portion of road **125** in the three-dimensional space of world **105**, with features nearer the center of the image being farther away from the user's viewpoint. In such a case, each set of articulated pyramidic panels are formed reitererately using the above described procedure.

Referring to FIGS. **12–13**, there is shown a third embodiment of the present invention which is similar to that of FIG. **5** and in which "pyramidic panels" $145_1'$, $145_2'$, $145_3'$ and $145_4'$ have been now multi-segmented into sections 205_{1-4}, 210_{1-4}, $205_{1-4}'$, and $210_{1-4}'$, respectively, with the images in original panels 145_{1-4} then texture-mapped into the corresponding translated sections of the pyramidic panel structure, as discussed herein below. It should be recalled that the pyramidic panel structure represents the three-dimensional mapping (x,y,z) of two-dimensional image **115** onto image screen or panel **110** (x,y). Advantageously, the embodiment of FIGS. **12–13** minimizes the depth profile of the pyramidic panel structure along the z-axis. Unlike the embodiment of FIG. **5**, the depth profile of this third embodiment does not substantially vary with changes in the user's viewpoint, V. In the exemplary embodiment of FIG. **5**, recall that distorting image **115** so as to move the vanishing point from P to P' results in the pyramidic panel structure forming a four-sided pyramid. The base of the pyramid is fixed and corresponds to original screen or panel **110**, with its peak located at P' and moves in concert with the viewer's current location, V. As the user's viewpoint moves

along the z-axis closer to and farther from two-dimensional image **115**, the image's new vanishing point P' moves farther from and closer to the user's viewpoint, respectively. This latter movement causes the depth profile along the z-axis of the pyramidic panel structure to vary accordingly. Unfortunately, this variation in depth profile can undesirably and/or unexpectedly occlude from the user's view objects in the virtual world, or cause objects to occlude other features in the virtual world inasmuch as the corresponding images in the panels are distorted, as discussed above herein.

To obviate the aforementioned problem, "pyramidic panels" 145_{1-4}', 145_2', 145_3' and 145_4' have been multi-segmented into sections 205_{1-4}, 210_{1-4}, 205_{1-4}', and 210_{1-4}' respectively. Each section is then translated along the z-axis to a predetermined distance towards or away from the user's viewpoint, V, but importantly of the same orientation as the original section. For example, segmented sections 205_{1-4} and 205_{1-4}' may each have one of its outer edge along the x-axis translated to lie on the x,y plane of screen or panel **110**, as shown in phantom in FIG. **12**. As the user moves to a new viewpoint, each section in effect pivots about that edge along the x-axis, which edge lies on the surface of panel **110**. Similarly, section 210_{1-4} and 210_{1-4}' may each have one of it outer edge along the y-axis lying on the surface of panel **110**. Alternatively, sections 205_{1-4}, and 205_{1-4}' may be centered along panel **110**, as depicted in FIG. **14**. Likewise, sections 210_{1-4} and 210_{1-4}' may be similarly translated, but for the sake of clarity are not shown in FIGS. **12** and **14**.

Still further, each of sections 205_{1-4} and 205_{1-4}' may in effect be rotated or pivoted about its other edge along the x-axis as the user moves to a new viewpoint, V, or, in general, about an axis parallel with an edge along the x-axis of the corresponding section. Again, this latter axis may, but does not have to, lie on the surface of panel **110**. Regardless of the segmenting method chosen, however, translating each section towards or away from the user's viewpoint significantly reduces the depth profile of the pyramidic panel structure along the z-axis, such as depicted in FIG. **12** from, for example, T_2 to T_1.

In still another embodiment of the present invention, sections 205_{1-4} and 205_{1-4}' may each be translated a different distance along the z-axis, as illustrated in FIG. **15**. Although not shown, sections 210_{1-4} and 210_{1-4}' may likewise be translated. Those skilled in the art will readily understand that doing so advantageously allows the user's viewpoint, V, to extend in front of panel **110** inasmuch as segmented sections corresponding to the image's center may be offset and located closer to the user's viewpoint, V, than the outer sections.

Also, note that segmenting the pyramidic panel structure into a greater number of smaller sections accordingly only further reduces the depth profile, which asymptotically approaches a zero thickness. It is contemplated that the number of sections that the panel structure is divided into may be chosen empirically based on image content as well as the user's range of movement within the virtual world. Preferably, however, the panel structure is dynamically segmented in a reiterative manner. For example, once a user has chosen the maximum desired depth for the panel structure along the z-axis to minimize occlusion, each panel is then reiteratively segmented into a greater number of smaller sections until the depth profile is reduced to the maximum depth profile desired.

In accordance with the principles of the invention, it should be clearly understood, however, that to maintain the apparent integrity of two-dimensional image **115** when texture-mapping the image onto the segmented sections, each segmented sections 205_{1-4}, 205_{1-4}', 210_{1-4}, and 210_{1-4}' is scaled accordingly with respect to the user's current viewpoint, V, so as to appear to be of the same size as the original corresponding section. This scaling or transform is given by:

$$S_t = S_p \frac{T_t}{T_p}$$

where S_p is the size of the original pyramidic section; S_t is the size of the translated, segmented pyramidic panel section; T_p is distance to the original pyramidic section from the user's viewpoint, V; and T_t is the distance to the translated, segmented pyramidic section. In other words, each segmented, translated section is scaled by the ratio T_t/T_p. Of course, as the user moves within the world, pyramidic panels 145_{1-4}' are accordingly re-segmented, translated, and then scaled with respect to the user's new viewpoint, V. Then, the images in original panels 145_{1-4} are again accordingly texture-mapped into the corresponding translated sections 205_{1-4}, 205_{1-4}', 210_{1-4}, and 210_{1-4}' of the pyramidic panel structure.

In the above embodiments, distorting two-dimensional image **115** according to the movement of the user's viewpoint results in different portions of the image being accordingly "expanded" or "compressed" when texture-mapping image **115** onto the corresponding pyramidic panels, as discussed above herein. Also, as the user's viewpoint moves along the z-axis closer to two-dimensional image **115**, the image is accordingly scaled or "enlarged" to make objects in the image appear closer to the user. Note that doing so requires scaling the x and y components of the objects accordingly as a function of their distance (z-axis) to the user's viewpoint. To illustrate these later aspects of the present invention, shown in FIG. **16** is screen **110** with two-dimensional image **115** displayed therein having a resolution of M×N pixels, e.g., 1200×1200. Now, as shown in FIG. **17**, moving along the z-axis closer to the center of the image and then texture-mapping the corresponding portions of image **115** onto pyramidic panels 145_{1-4}' requires enlarging and distorting the image such that only a small center portion of the enlarged and distorted image is displayed on screen **110**, which in effect lowers the observable image resolution. This is so since the image only has a finite number of pixels, and fewer pixels are displayed on the same size screen. One solution to this latter problem is using high resolution images which allows the user to travel towards the center of the image without losing image quality, but it results in the perimeter of the image having a resolution higher that needed since enlarging the image causes the perimeter of the image to be outside the field of view of the observer and, therefore not displayed on the screen. This higher than needed resolution requires more memory to store image **115** as well as additional computational time to perform the texture mapping, among other things. Of course, using lower resolution images would require less memory and computational time, but it typically leads to poor image quality near the center of image where the image is typically enlarged or distorted the greatest.

Referring to FIG. **18**, there is shown still another embodiment of the present invention which obviates the aforementioned problem by using a two-dimensional image having a "hierarchical image resolution," thereby allowing segmented portions of the image to have a resolution according to its location within the image. In this manner, a fine

resolution can be used for portions of image **115** near the center of the image whereas a coarse resolution can be used for the perimeter, thereby minimizing the total texture-map size or pixel-map size. It should be clearly understood that this hierarchical image resolution is equally applicable to any one of the above pyramidic panel structures discussed herein above. In this aspect of the present invention, two-dimensional image **115** has been segmented into resolution regions $\mathbf{215}_{1\text{-}4}$ each having a rectangular shape, although other shapes are readily adaptable for the purposes of this invention. The corresponding portions of image **115** within resolution regions $\mathbf{215}_{1\text{-}4}$ have different resolutions such that portions of the image closer to the center of the image have a finer resolution than portions farther away. For example, resolution regions $\mathbf{215}_{1\text{-}4}$ may have image pixel resolutions of $m_1 \times m_1$, $m_2 \times m_2$, $m_3 \times m_3$ and $m_4 \times m_4$, respectively, where $m_1 \geqq m_2 \geqq m_3 \geqq m_4$. In this manner, distorting or enlarging portions of the image near the center of the image or where the image's vanishing point is typically located does not substantially affect the observed image resolution inasmuch as a greater number of pixels are contained in the image.

It is contemplated that the number of resolution regions that image **115** is segmented into as well as the pixel resolution therein may be, for example, chosen empirically based on image content as well as the user's range of movement within the virtual world. For example, portions of the image near the center can have a resolution of 4800×4800, while portions near the perimeter only a resolution of 1200×1200. Furthermore, the resolution for resolution regions $\mathbf{215}_{1\text{-}4}$ may be dynamically chosen according to the amount of distortion or enlargement performed on the image. That is, each region is allocated a finer resolution with a greater distortion or enlargement, and vice-a-versa.

Of course, various computer storage techniques may be used to set the image resolution within regions $\mathbf{215}_{1\text{-}4}$. For example, image **115**, typically a still photograph, picture or video frame, may be captured with a resolution of 4800×4800 pixels or greater, and then a subset of those pixels used to achieve a desired lower resolution.

The foregoing merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangement which, although not explicitly describe or shown herein, embody the principles of the invention and are included within its spirit and scope.

What is claimed is:

1. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including an object depicted in perspective, said image being such that features of the object closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

segmenting the two-dimensional image into a plurality of sections;

setting the pixel resolution of each of said plurality of sections according to its location within the two-dimensional image;

determining a vector, $\overline{C}$, corresponding to the direction of said perspective object in the three-dimensional world;

projecting towards said panel the vector, $\overline{C}$, from the two-dimensional image's ideal viewing point, IVP, the intersection of said vector, $\overline{C}$, with the panel being denoted as the image's vanishing point, P;

segmenting said panel into triangular regions intersecting at the image's vanishing point, P;

determining the current viewpoint, V, of the user and projecting a vector, $\overline{T}$, from the image's ideal viewing point, IVP, to the current viewpoint, V;

determining a new vanishing point for the two-dimensional image in accordance with the following relationship $P'=P+\overline{T}$;

distorting the triangular regions in the space of the three-dimensional world such that they intersect at the new vanishing point, P';

texture-mapping the two-dimensional image in the triangular regions onto said distorted triangular regions; and

displaying the computer graphics along with the two-dimensional image.

2. The invention as defined in claim **1** wherein the pixel resolution of each of said plurality of sections is set according to its location relative to the center of the two-dimensional image.

3. The invention as defined in claim **1** wherein the pixel resolution of each of said plurality of sections is set such that sections closer to the center of the two-dimensional image have a higher pixel resolution than sections farther away.

4. The invention as defined in claim **1** wherein each of said plurality of section is substantially rectangular in shape.

5. The invention as defined in claim **1** wherein the vanishing point is located at or near the center of the two-dimensional image.

6. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, comprising the steps of:

determining the current viewpoint of the user, V;

dividing the panel into triangular regions;

distorting the triangular regions to form pyramidic panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;

segmenting each of said pyramidic panels into a plurality of sections;

translating each of said plurality of sections of said pyramidic panels towards, or away from, said current viewpoint of the user, V;

segmenting the two-dimensional image into sections;

adjusting the pixel resolution in each of said sections of the two-dimensional image according to its location relative to the center of the two-dimensional image;

texture-mapping the two-dimensional image onto the plurality of sections of the pyramidic panels;

scaling each of said plurality of sections of said pyramidic panels in accordance with the following relationship $S_t = S_p T_t / T_p$, where S_p is the size of the section; S_t is the size of the translated section; T_p is distance to the section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V; and

displaying the computer graphics along with the two-dimensional image.

7. The invention as defined in claim **6** wherein the pixel resolution of each of said plurality of sections is set such that sections closer to the center of the two-dimensional image have a higher pixel resolution than sections farther away.

8. The invention as defined in claim **6** wherein each of said plurality of section is substantially rectangular in shape.

9. The invention as defined in claim **6** wherein said segmenting step includes resegmenting said pyramidic pan-

els into a greater number of smaller sections until the depth profile of the pyramidic panel structure formed from said panels reaches a predetermined level.

10. The invention as defined in claim **6** wherein an outer edge of each of said plurality of sections of said pyramidic panels is located on the surface of a predetermined plane.

11. The invention as defined in claim **10** wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

12. The invention as defined in claim **6** wherein the center of each of said plurality of sections of said pyramidic panels is substantially located at the surface of a predetermined plane.

13. The invention as defined in claim **12** wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

14. The invention as defined in claim **6** further comprising determining a vector, $\overline{C}$, corresponding to the direction of a portion of a path contained within the two-dimensional image, and projecting toward the panel the vector, $\overline{C}$, from the image's ideal viewing point, IVP, the intersection of said vector, $\overline{C}$, with the panel being denoted as the image's vanishing point, P.

15. The invention as defined in claim **6** wherein said distorting of the triangular regions in said distorting step includes determining a new vanishing point, P', for said two-dimensional image in accordance with the following relationship $P'=P+\overline{T}$, wherein $\overline{T}$ is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

* * * * *

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(12) **United States Patent**
Edmark

(10) **Patent No.: US 6,236,402 B1**
(45) **Date of Patent: May 22, 2001**

(54) **DISPLAY TECHNIQUES FOR THREE-DIMENSIONAL VIRTUAL REALITY**

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(73) Assignee: **Lucent Technologies, Inc.**, Murray Hill, NJ (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **09/160,758**

(22) Filed: **Sep. 25, 1998**

Related U.S. Application Data

(63) Continuation-in-part of application No. 09/107,059, filed on Jun. 30, 1998.

(51) **Int. Cl.**[7] **G06T 17/00**
(52) **U.S. Cl.** **345/419**; 345/427
(58) **Field of Search** 345/418, 419, 345/420, 427, 433, 139, 473, 474

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* cited by examiner

Primary Examiner—Cliff N. Vo
(74) *Attorney, Agent, or Firm*—J. De La Rosa

(57) **ABSTRACT**

A limitation of using two-dimensional images, such as videos or photographs, to represent portions of a three-dimensional world occurs when the user moves within the world and views the world from a location different than from the original context of the two-dimensional image, i.e., from a location different than the image's ideal viewing point (IVP). View changes result in the image not aligning well with the surrounding objects of the three-dimensional world. This limitation is overcome by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a pyramidic panel structure. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and its surroundings. To minimize the depth profile of the pyramidic panel structure, the structure may be segmented into sections and each section translated towards, or away from, the user's viewpoint.

32 Claims, 12 Drawing Sheets

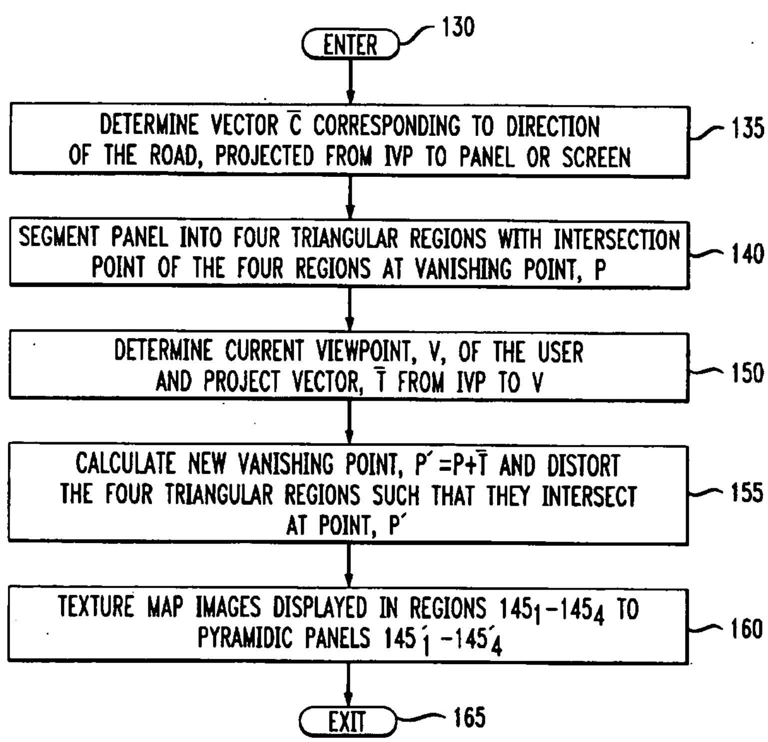


FIG. 1

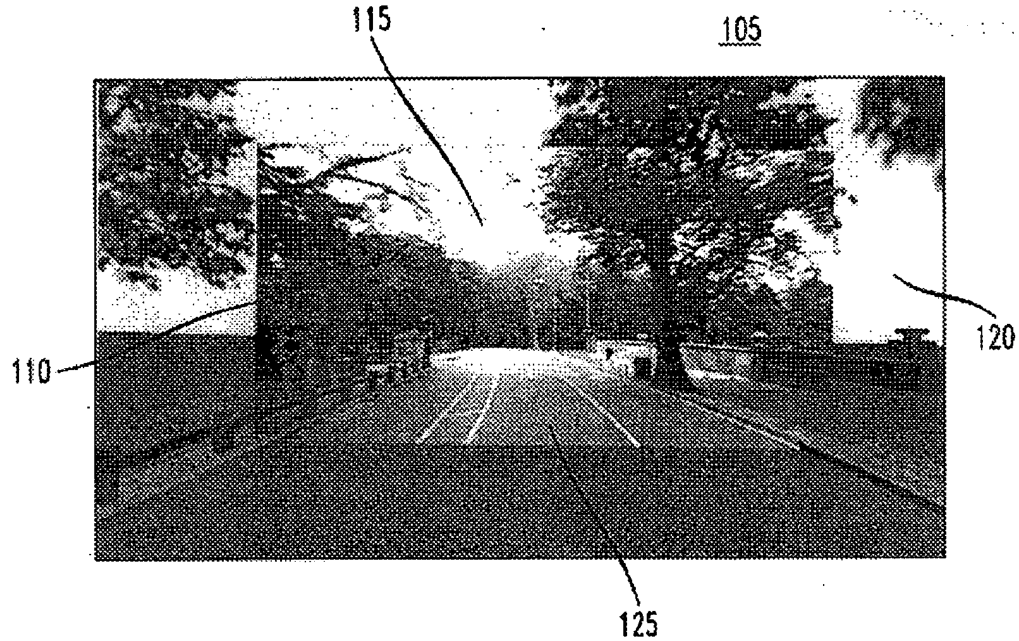


FIG. 2

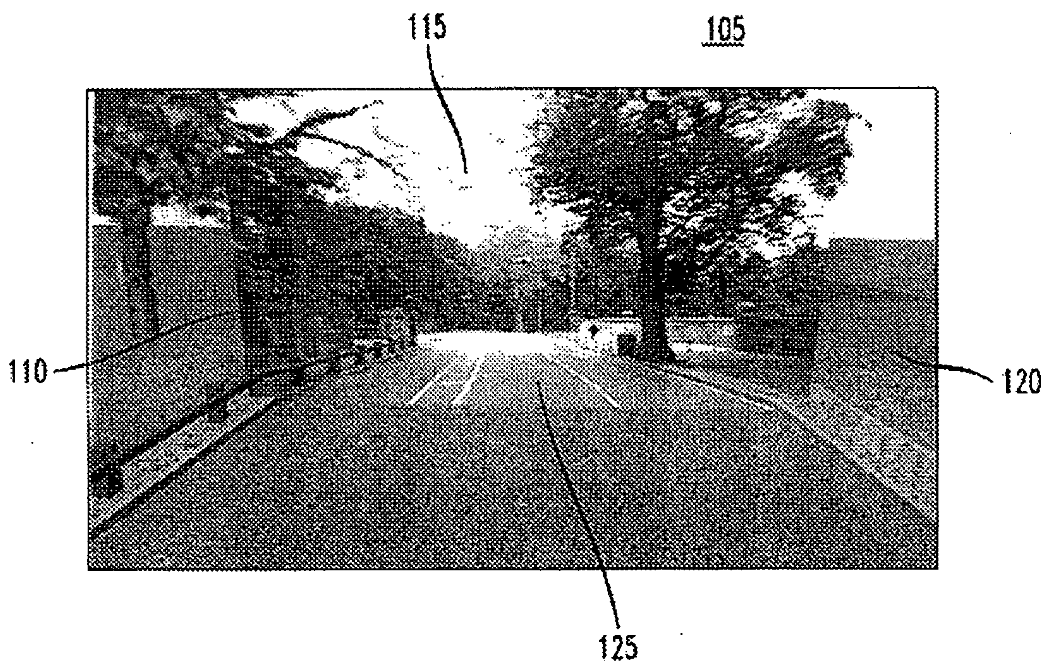


FIG. 3

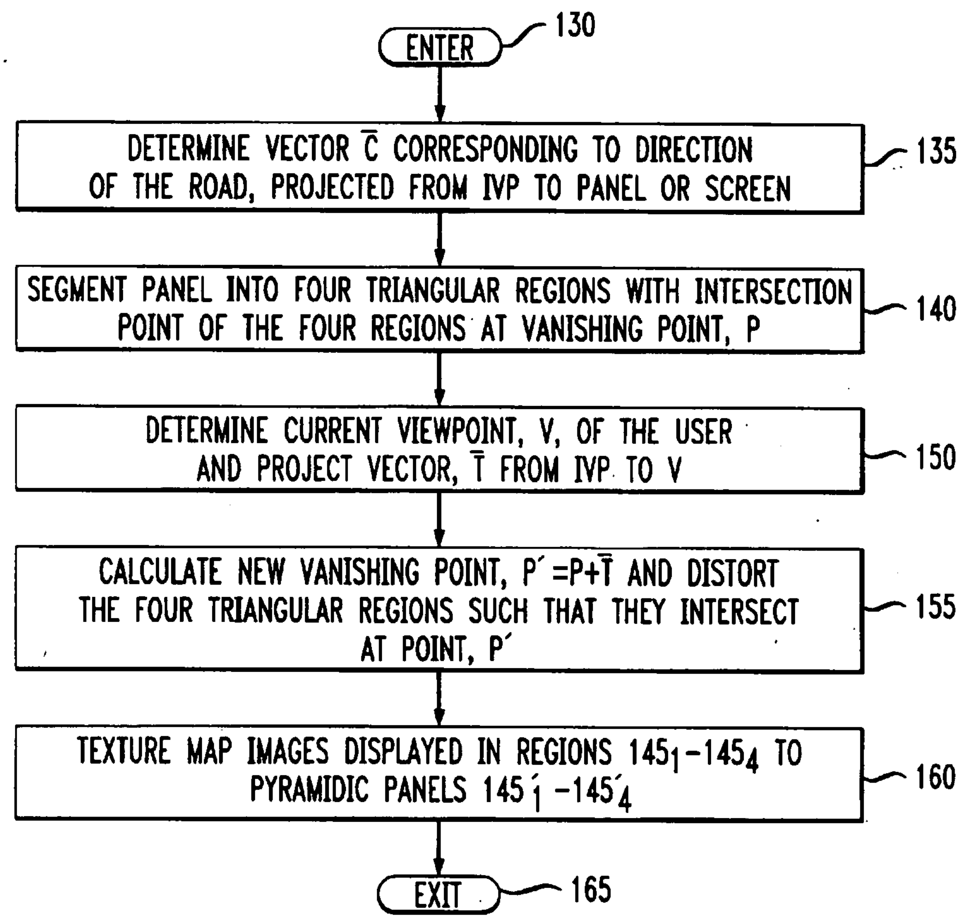
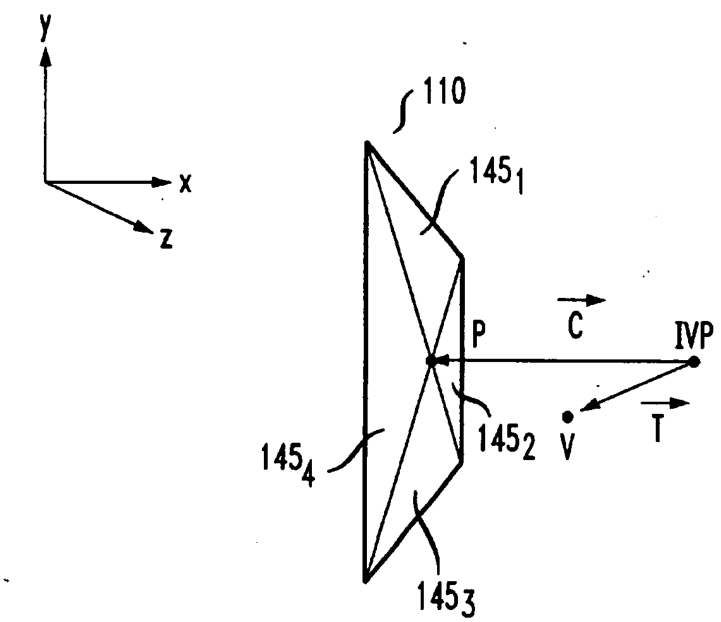
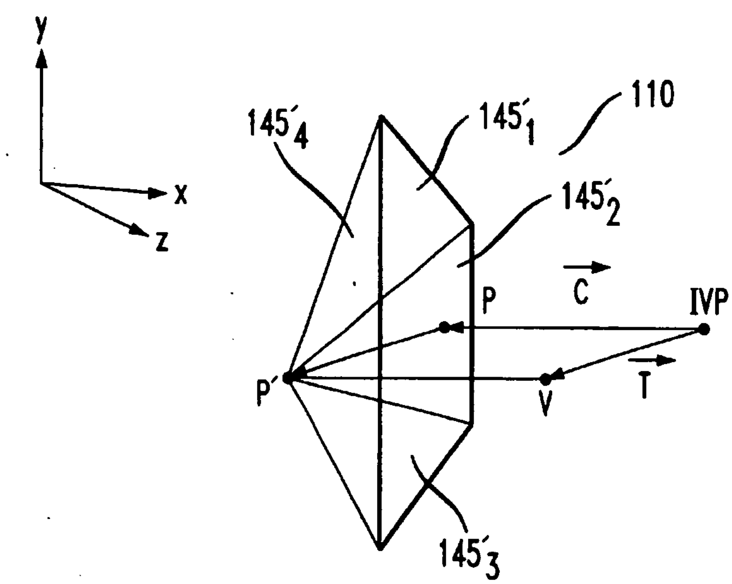

ENTER
130
DETERMINE VECTOR $\bar{C}$ CORRESPONDING TO DIRECTION OF THE ROAD, PROJECTED FROM IVP TO PANEL OR SCREEN
135
SEGMENT PANEL INTO FOUR TRIANGULAR REGIONS WITH INTERSECTION POINT OF THE FOUR REGIONS AT VANISHING POINT, P
140
DETERMINE CURRENT VIEWPOINT, V, OF THE USER AND PROJECT VECTOR, $\bar{T}$ FROM IVP TO V
150
CALCULATE NEW VANISHING POINT, $P' = P + \bar{T}$ AND DISTORT THE FOUR TRIANGULAR REGIONS SUCH THAT THEY INTERSECT AT POINT, P′
155
TEXTURE MAP IMAGES DISPLAYED IN REGIONS 145_1–145_4 TO PYRAMIDIC PANELS $145'_1$–$145'_4$
160
EXIT
165

FIG. 4



y
x
z
110
145_1
P
C
IVP
145_2
V
T
145_4
145_3

FIG. 5



y
x
z
110
$145'_4$
$145'_1$
$145'_2$
P
C
IVP
P'
V
T
$145'_3$

FIG. 6A

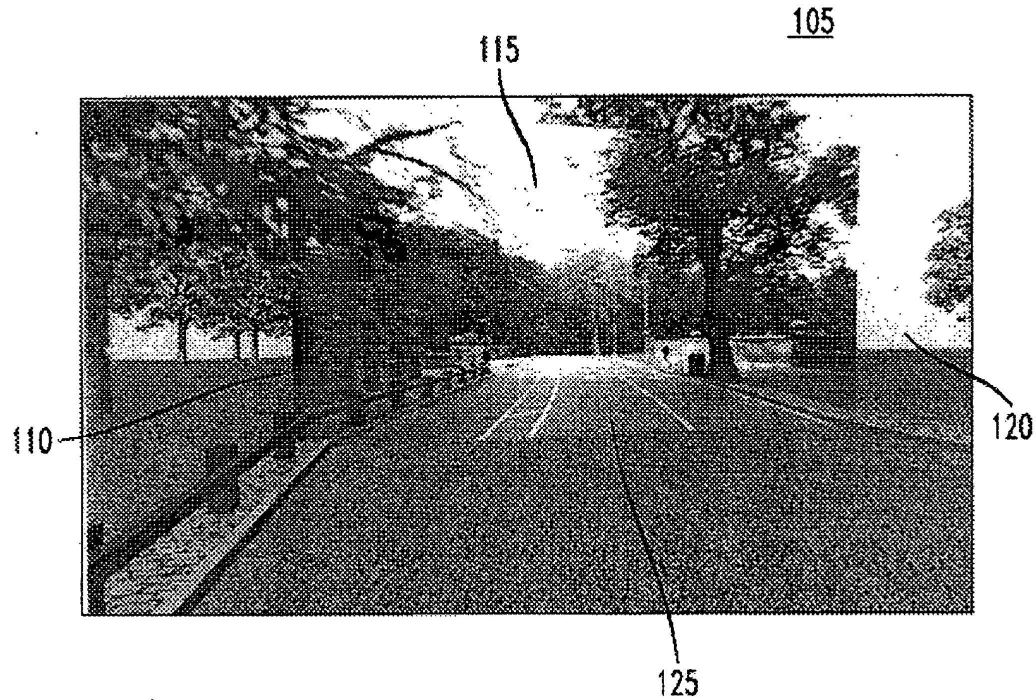


FIG. 6B

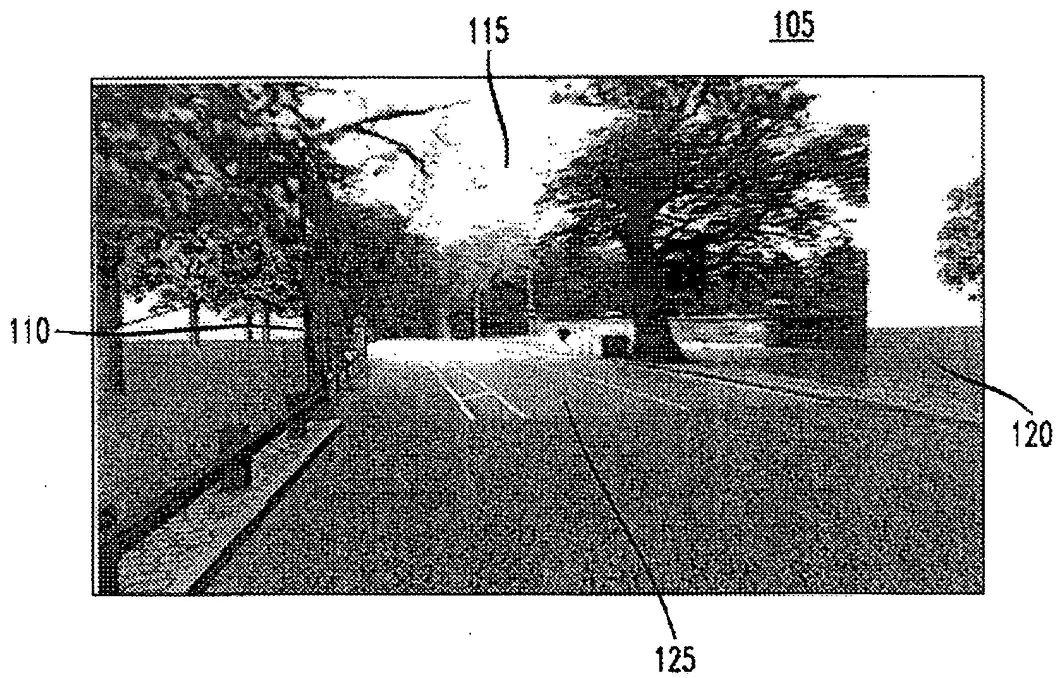


FIG. 7A

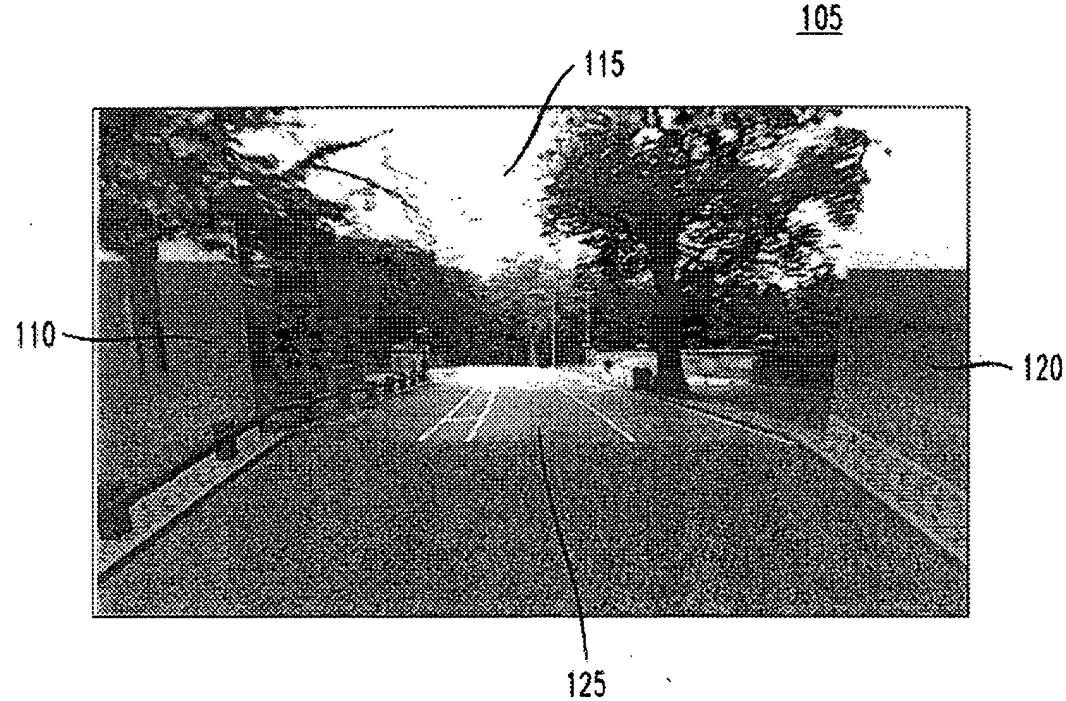


FIG. 7B

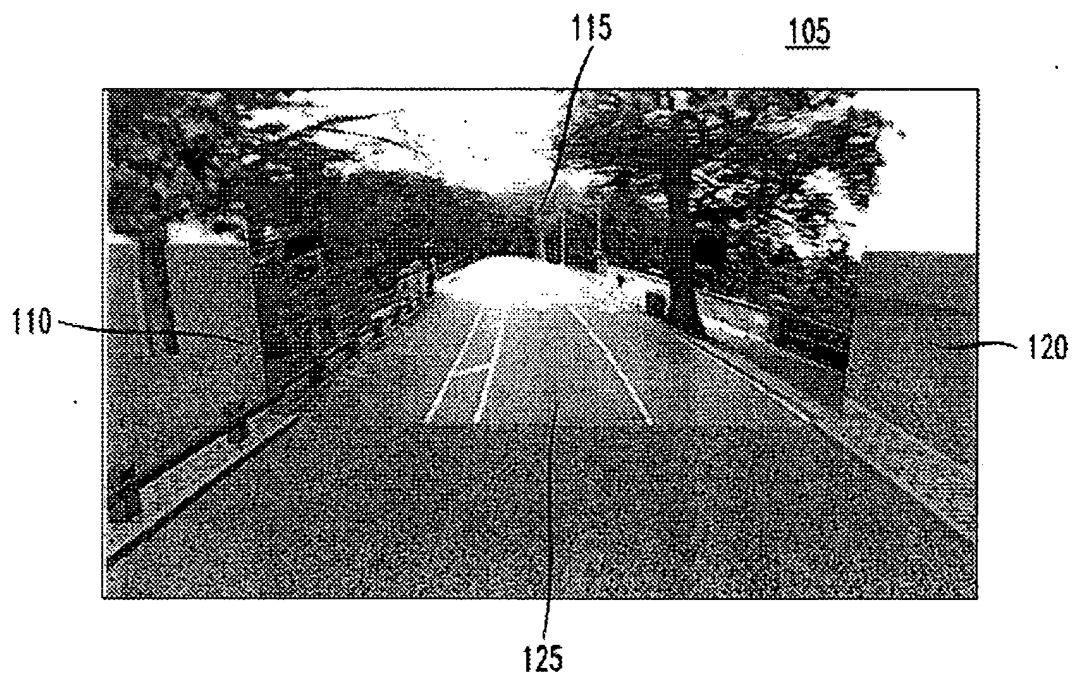


FIG. 8A

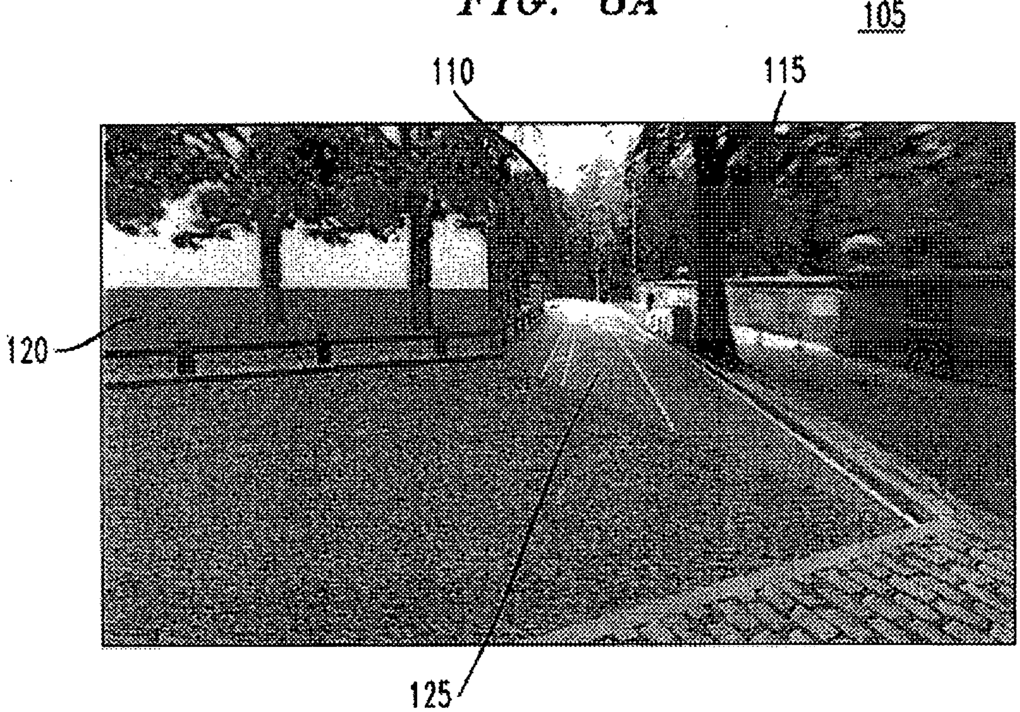


FIG. 8B

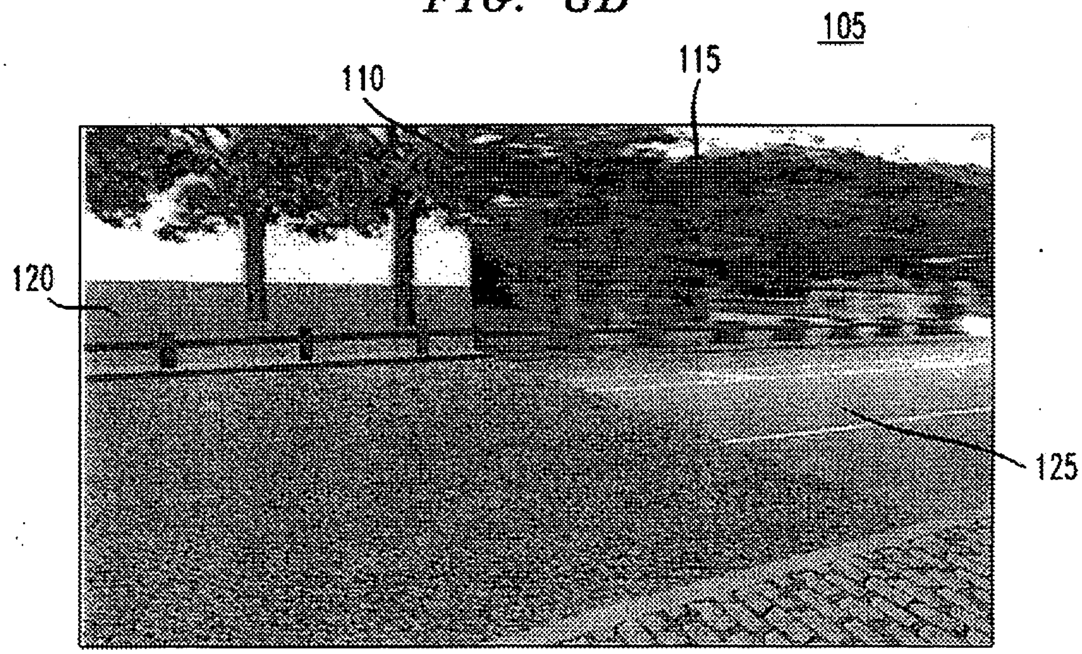


FIG. 9

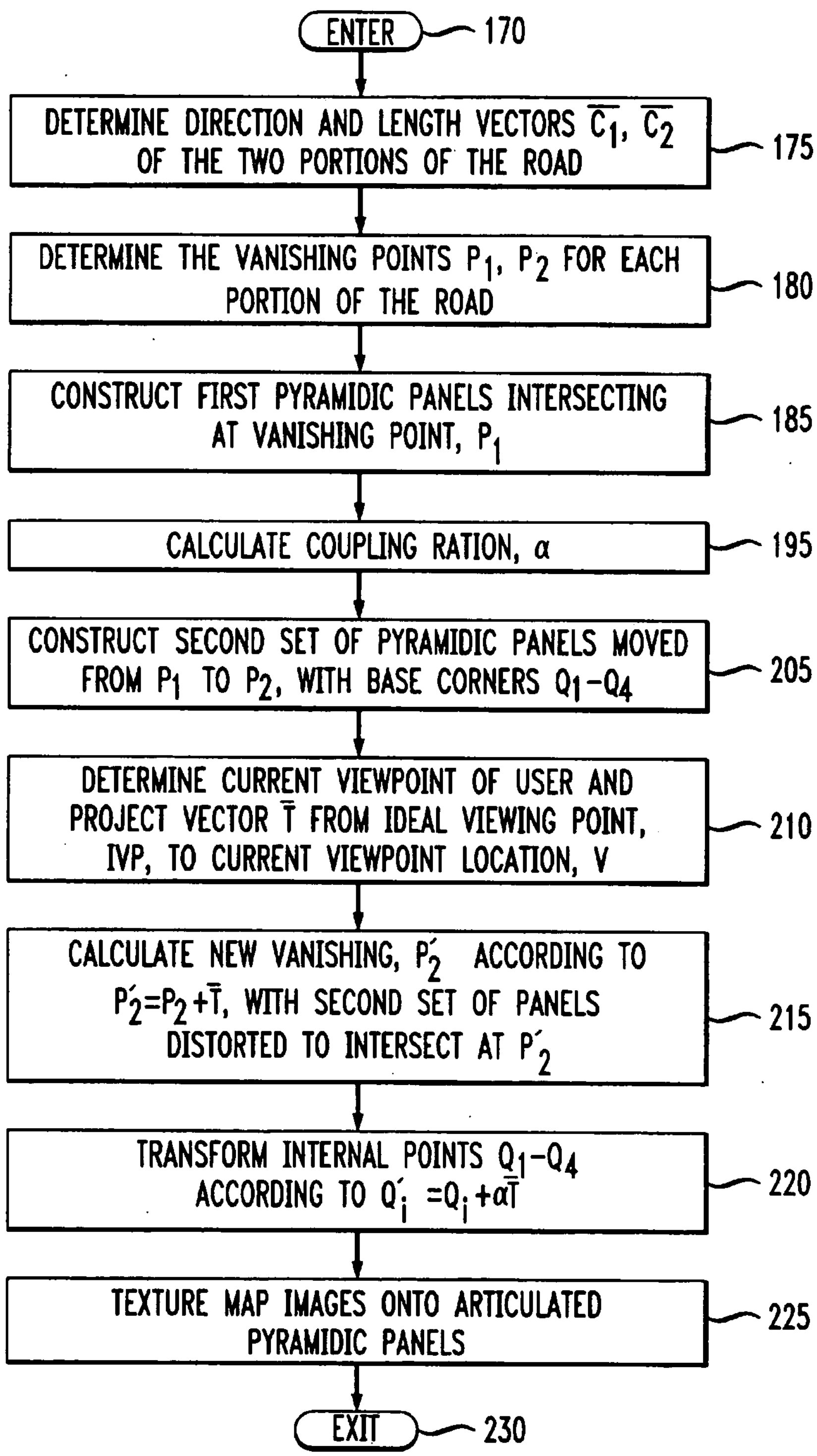

ENTER
170
DETERMINE DIRECTION AND LENGTH VECTORS $\overline{C_1}$, $\overline{C_2}$ OF THE TWO PORTIONS OF THE ROAD
175
DETERMINE THE VANISHING POINTS P_1, P_2 FOR EACH PORTION OF THE ROAD
180
CONSTRUCT FIRST PYRAMIDIC PANELS INTERSECTING AT VANISHING POINT, P_1
185
CALCULATE COUPLING RATION, α
195
CONSTRUCT SECOND SET OF PYRAMIDIC PANELS MOVED FROM P_1 TO P_2, WITH BASE CORNERS Q_1–Q_4
205
DETERMINE CURRENT VIEWPOINT OF USER AND PROJECT VECTOR $\overline{T}$ FROM IDEAL VIEWING POINT, IVP, TO CURRENT VIEWPOINT LOCATION, V
210
CALCULATE NEW VANISHING, P'_2 ACCORDING TO $P'_2=P_2+\overline{T}$, WITH SECOND SET OF PANELS DISTORTED TO INTERSECT AT P'_2
215
TRANSFORM INTERNAL POINTS Q_1–Q_4 ACCORDING TO $Q'_i=Q_i+\alpha\overline{T}$
220
TEXTURE MAP IMAGES ONTO ARTICULATED PYRAMIDIC PANELS
225
EXIT
230

FIG. 10

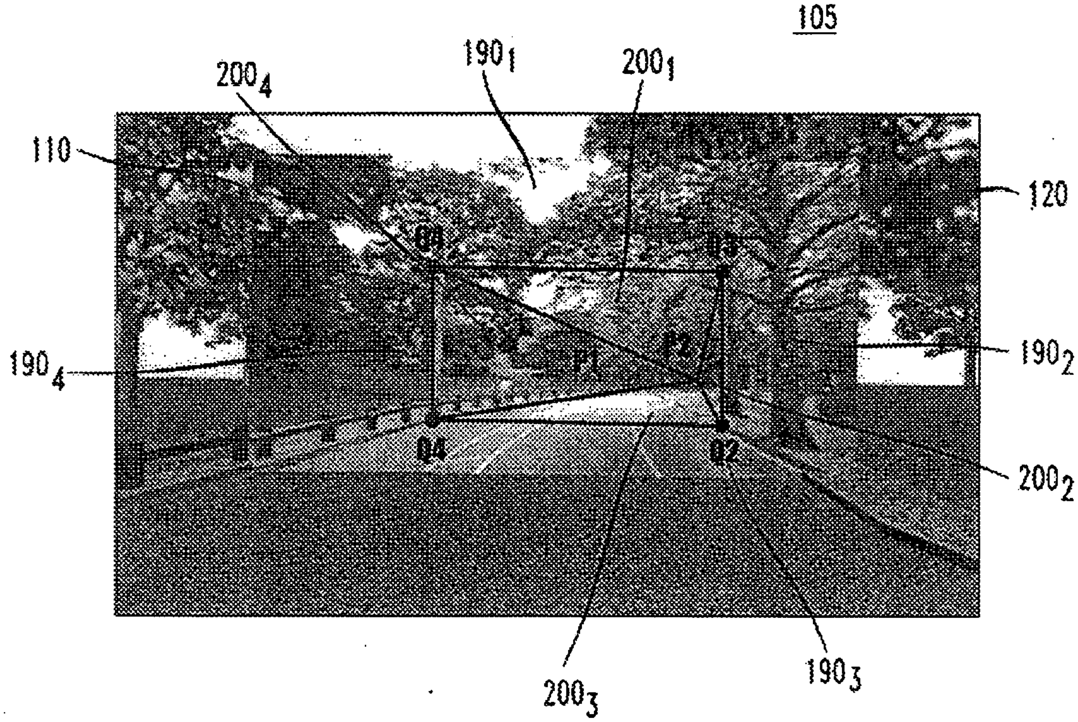

105
190_1
200_1
200_4
110
120
Q1
Q3
P1
P2
190_4
190_2
Q4
Q2
200_2
200_3
190_3

FIG. 11

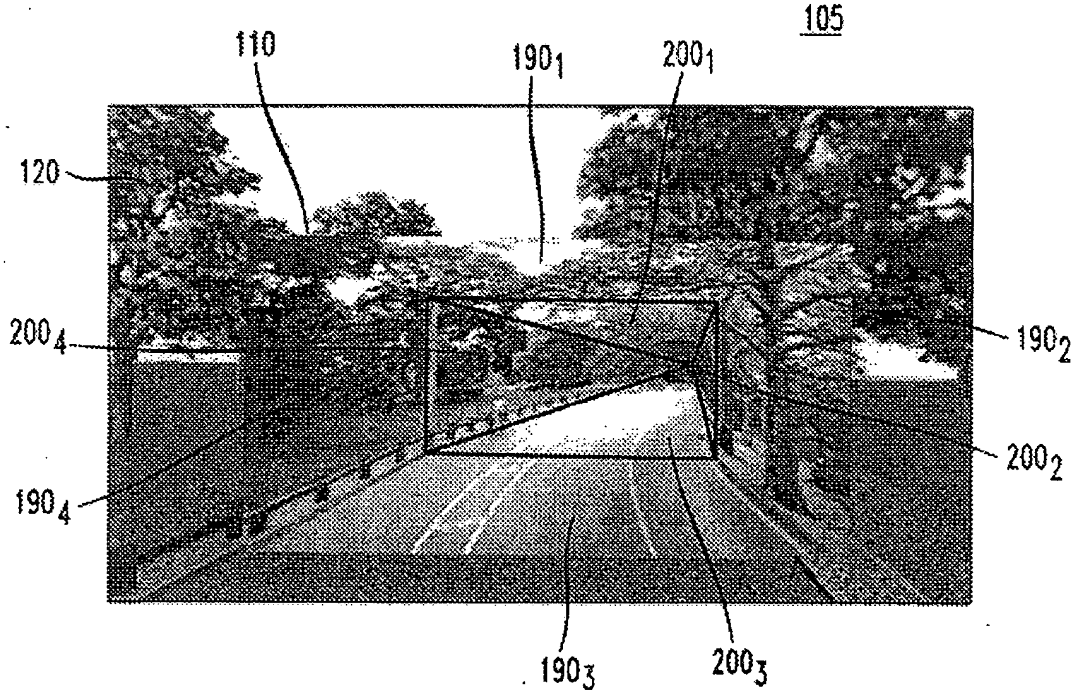

105
110
190_1
200_1
120
200_4
190_2
200_2
190_4
190_3
200_3

FIG. 12

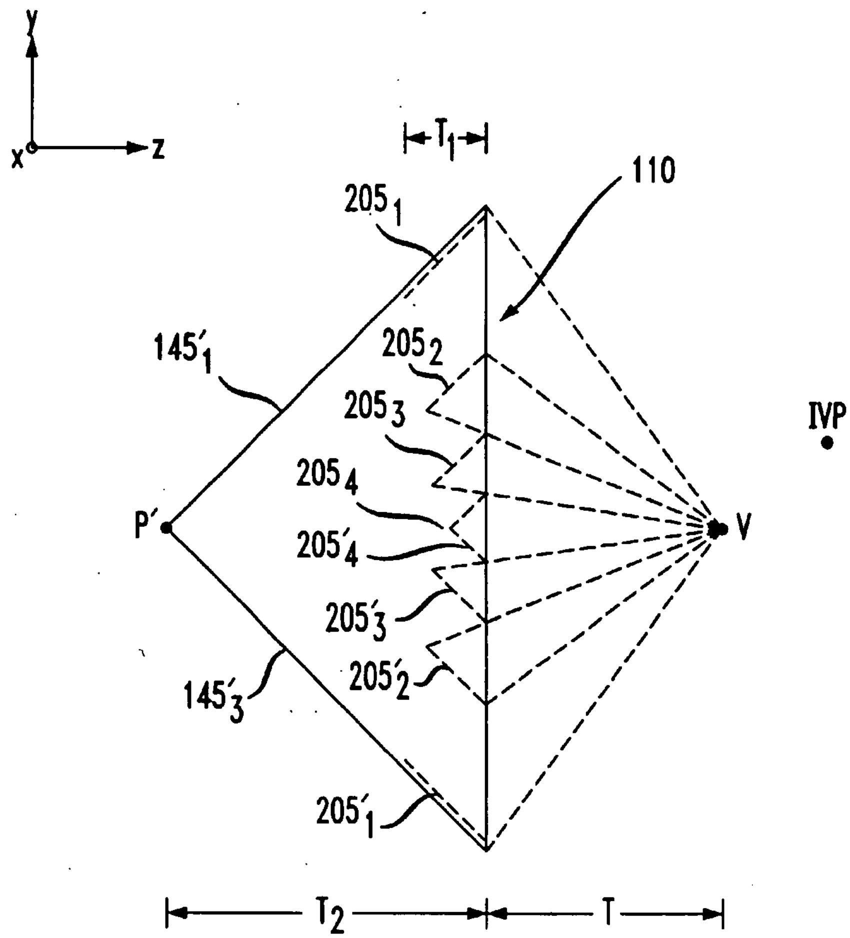

y
x
z
T_1
110
205_1
$145'_1$
205_2
205_3
IVP
205_4
P'
V
$205'_4$
$205'_3$
$205'_2$
$145'_3$
$205'_1$
T_2
T

FIG. 13

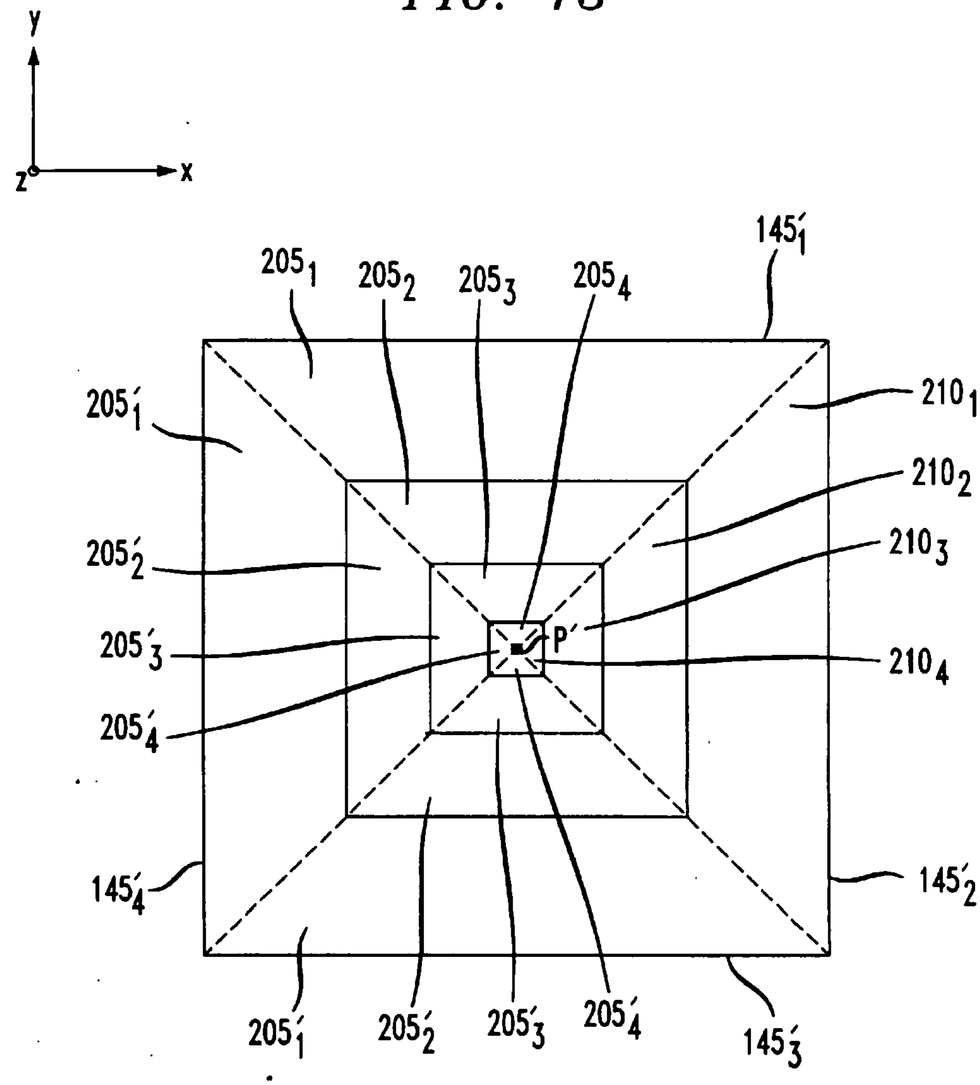

y
z
x
205_1
205_2
205_3
205_4
$145'_1$
$205'_1$
210_1
210_2
$205'_2$
210_3
$205'_3$
P'
210_4
$205'_4$
$145'_4$
$145'_2$
$205'_1$
$205'_2$
$205'_3$
$205'_4$
$145'_3$

FIG. 14

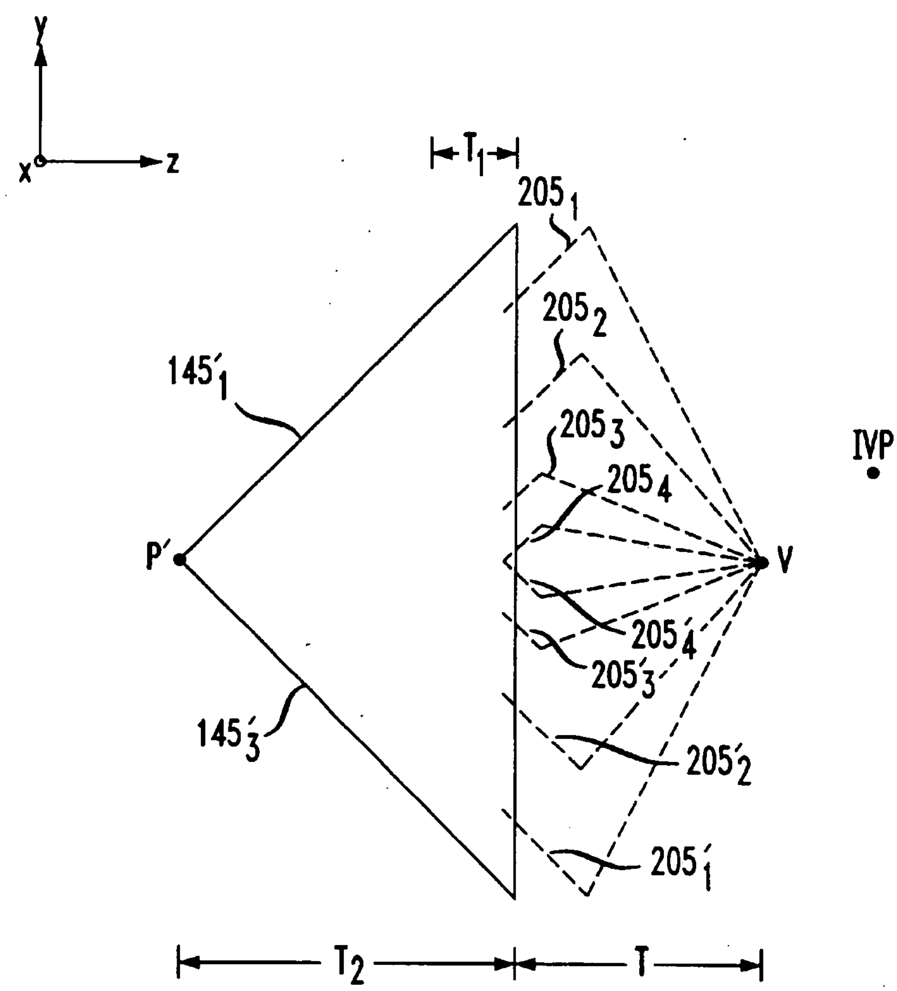
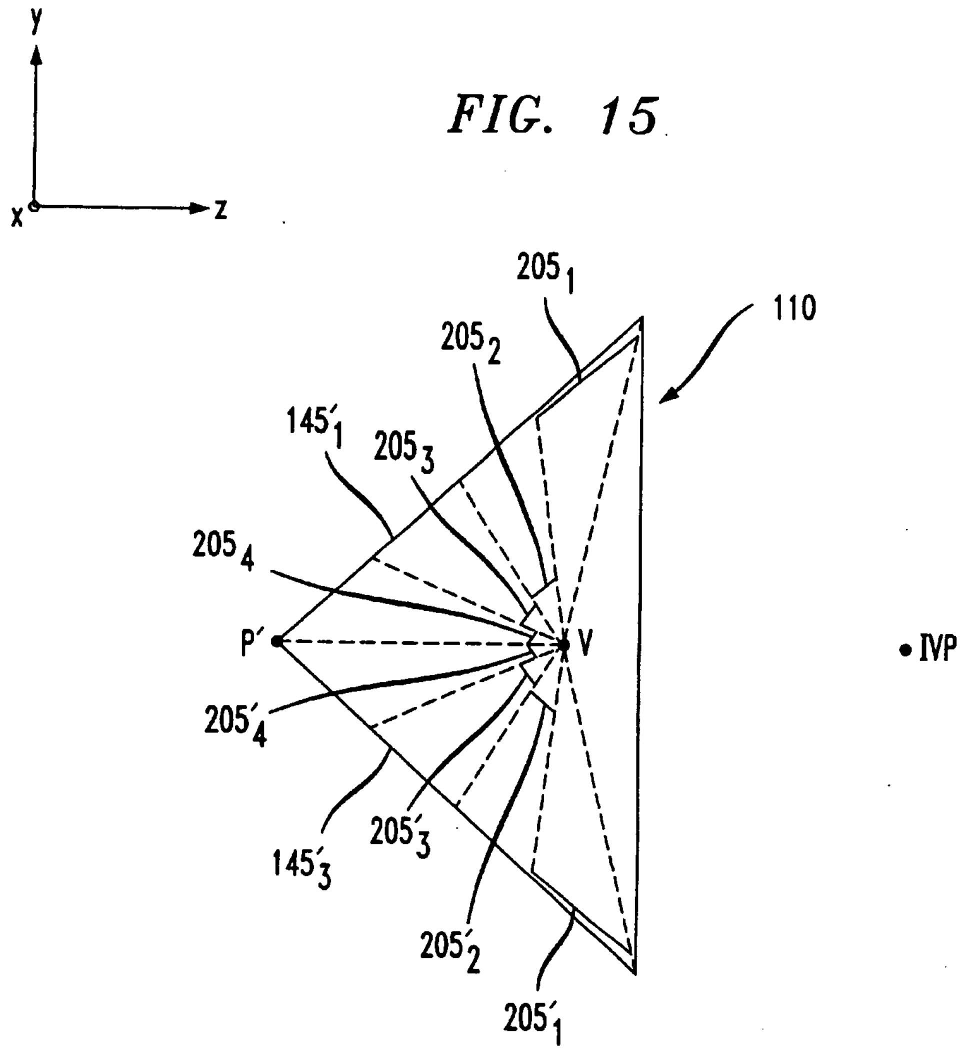

y
x
z
T_1
205_1
205_2
205_3
205_4
$145'_1$
IVP
P'
V
$205'_4$
$205'_3$
$145'_3$
$205'_2$
$205'_1$
T_2
T

FIG. 15


y
x
z
205_1
110
205_2
$145'_1$
205_3
205_4
P'
V
• IVP
$205'_4$
$145'_3$
$205'_3$
$205'_2$
$205'_1$

DISPLAY TECHNIQUES FOR THREE-DIMENSIONAL VIRTUAL REALITY

CROSS-REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of U.S. patent application Ser. No. 09/107,059 filed on Jun. 30, 1998 (Case Edmark-2). The above-identified co-pending application, which is commonly assigned, is incorporated herein by reference.

TECHNICAL FIELD

This invention relates to the integration of three-dimensional computer graphics and a two-dimensional image to provide a realistic three-dimensional virtual reality experience.

BACKGROUND OF THE INVENTION

The display of a three-dimensional virtual reality world to a user requires considerable computation power, and it is typically costly to develop the necessary highly detailed models required for doing so. In order to simplify the problem, two-dimensional images, such as videos or photographs, may be used to represent or simulate portions of the three-dimensional world. A great reduction in computation power and cost can be achieved by such an arrangement.

SUMMARY OF THE INVENTION

A limitation of such a world occurs when a user moves within the world and views the world from a location different than the original context of a two-dimensional image which has been carefully calibrated to "fit into" the world. View changes, such as from a location different than the image's ideal viewing point, result in the image not aligning or fitting well with the surrounding objects of the three-dimensional world. We have recognized that, in accordance with the principles of the invention, viewpoint changes may be dealt with by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user using a novel "pyramidic panel structure." In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and the surroundings of the world. In certain embodiments, the pyramidic panel structure may be segmented into sections, each translated towards or away from the user's viewpoint and then scaled, so as to minimize the depth profile of the pyramidic panel structure.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. 1 shows an example of that which a user sees when a user views the world from the ideal viewing point for a two-dimensional image representing a portion of the world;

FIG. 2 shows an example of that which a user sees when a user moves within the world of FIG. 1 and views the two-dimensional image from a location different than the image's ideal viewing point, without the use of the present invention;

FIG. 3 shows an exemplary process, in accordance with the principles of the invention, for distorting the two-dimensional image using a pyramidic panel structure so as to adjust the image's vanishing point in accordance with the movement of the user;

FIGS. 4 and 5 depict the pyramidic panel structure of the present invention for distorting the two-dimensional image so as to adjust the image's vanishing point, in accordance with the movement of the user;

FIGS. 6A–B depict examples of that which a user sees when a user views the world from a location left of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 7A–B depict examples of that which a user sees when a user views the world from a location above the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. 8A–B depict examples of that which a user sees when a user views the world from a location toward the front and the right of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIG. 9 shows an exemplary process, in accordance with the principles of the invention, for distorting a two-dimensional image using an articulated pyramidic panel structure so as to adjust multiple vanishing points in the image, in accordance with the movement of the user;

FIG. 10 depicts an example of the articulated pyramidic panel structure of the present invention;

FIG. 11 depicts an example of that which a user sees when a user views the world from a location away from the ideal viewing point of the two-dimensional image, with the use of the articulated pyramidic panel structure of the present invention;

FIGS. 12 and 13 depict side and front views, respectively, of the pyramidic panel structure of FIG. 5 with each panel segmented into a plurality of sections;

FIG. 14 depicts the pyramidic panel structure of FIG. 5, with each panel segmented into a plurality of sections having its centers located on the surface of a predetermined plane; and

FIG. 15 depicts the pyramidic panel structure of FIG. 5, with each panel segmented into a plurality of sections and each section translated a different distance toward the user's view point, V.

DETAILED DESCRIPTION

To better understand the invention, FIGS. 1–2 show examples of that which a user sees when the user moves within a three-dimensional virtual reality world (x,y,z) and views a two-dimensional image (x,y) representing a portion of the world from a location at the image's ideal viewing point (IVP), and then from a different location, i.e., a location different than the original context of the image. It should be understood that the two-dimensional image has been carefully calibrated to "fit into" the surroundings of the world. For simplification of terminology purposes, we shall use the term two-dimensional image to denote either a video clip or a photograph. In accordance with the principles of the invention, as the user moves away from the ideal viewing point, discontinuities between the two-dimensional image and its surroundings are minimized by distorting the image according to the movement of the user.

FIG. 1 shows an exemplary three-dimensional reality world **105**, which is a bicycle path in a park, e.g., Central Park in New York City. In representing world **105**, the present invention exploits a characteristic common for images consisting of views looking down the center of roads, streets or paths, which is that they may be treated as perspective, corridor-like images, with features closer to the center of the image being farther away from the viewer

along the z-axis. Accordingly, the bicycle path or road and its immediate vicinity are treated as a kind of three-dimensional, corridor-like image whose floor is formed by the roadbed, whose ceiling is formed by the sky, and whose sidewalls are formed by the roadside objects. In this manner, the principles of a simple point perspective can be used for distorting the landscape image in accordance with the movement of the viewer, as discussed herein below.

World **105** is divided into two portions, screen or panel **110** on which is shown or displayed a two-dimensional image **115**, such as a still photograph, picture, or a current frame of a video clip; and the remainder of the world **120**, which is represented using computer graphics techniques, and is thus referred to herein as computer graphics (CG Part) **120**. Within CG Part **120** there are various synthetic, three-dimensional landscapes or objects modeled in, for example, the Virtual Reality Modeling Language (VRML). Two-dimensional image **115** simulates landscape or terrain portions of the world **105**, here a virtual road or course **125** for walking, running or pedaling a bicycle.

Note that although three-dimensional world **105** cannot be actually rendered in a two-dimensional plane (x,y), it can be projected to and displayed on a two-dimensional plane so as to appear to have three dimensions (x,y,z). Accordingly, the techniques of the present invention are preferably employed with computers and software, which are sufficiently sophisticated to display images on a two-dimensional plane as having three dimensions. Note also that to make the world look realistic, computer graphics display techniques use the z component of objects to scale accordingly the x and y components as a function of its distance (z-axis) to the user's viewpoint.

Two-dimensional image **115** is carefully placed, cropped and sized to achieve continuity with the surrounding environment of the CG Part **120**. Note that the image is clipped so that the left and right edges of the road in CG Part **120** pass through the left and right bottom corners of the road, respectively, in image **115**. This clipping ensures that the roadbed maps to the floor of the hypothetical corridor. In so doing, portions at the boundary between two-dimensional image **115** and CG part **120** are co-planar, i.e., at the same distance away along the z-axis from the user's viewpoint. In "fitting" two-dimensional image **115** to CG part **120**, however, there exits only one viewpoint from which that image's content properly corresponds to the surrounding environment of CG Part **120**. This unique location is called the image's ideal viewing point (IVP). In FIG. **1**, two-dimensional image **115** is seen from its ideal viewing point, and from this view, image **115** aligns well with the surrounding objects of CG Part **120**.

Users, however, rarely view image **115** only from its idea viewing point. As the user moves within world **105**, such as left or right of road **125**, as they round curves, or move closer to or farther from the image, they see image **115** from positions other than its ideal viewing point. Absent the use of the present invention, such viewpoint changes would cause objects or features within image **115** to align improperly with the surrounding environment, as further illustrated in FIG. **2**.

In accordance with the principles of the invention, however, screen or panel **110** uses a display structure called a "pyramidic panel structure" for displaying two-dimensional image **115** within the surrounding three-dimensional space of the CG Part **105** so as to deal with viewpoint changes. The transformations associated with the pyramidic panel structure dynamically distort two-dimensional image **115** according to viewer's position so as to adjust the image's vanishing point with the viewer's movement. As the viewer moves from the image's ideal viewing point, these distortions act to limit discontinuities between image **115** and the surroundings of CG Part **120**.

FIG. **3** shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image **115** so as to adjust its vanishing point in accordance with the viewer's position. The process is entered at step **130** whenever it is determined that the viewer's position has changed.

Using the virtual world's road model of the CG Part **105**, a vector, $\overline{C}$, corresponding to the direction of road **125** is projected at step **135** from the image's ideal viewing point, IVP, to panel or screen **110** on which is displayed image **115**. Note that the panel is two-dimensional, but represents three-dimensional space with objects nearer the center of the image being farther away from the plane of the viewer. The panel structure is shown in FIG. **4**. The point of intersection with screen or panel **110** is the image's vanishing point, P. Note, however, that the vanishing point may be set visually by the user, if desired, or by other suitable computer graphics processing techniques known in the art. Next, in step **140**, screen or panel **110** is segmented into four triangular regions $\mathbf{145}_{1\text{-}4}$, one for each of the regions bordering CG Part **120**, with the intersection point of the four regions located at the vanishing point, P.

Thereafter in step **150**, the current viewpoint of the user, V, is determined, and a vector $\overline{T}$ projected from the ideal viewing point, IVP, to the viewer's current location, V. In accordance with the principles of the invention, as the viewer moves, a new vanishing point P' is calculated as $P'=P+\overline{T}$. The four triangular regions $\mathbf{145}_{1\text{-}4}$ are distorted in the three-dimensional space of the virtual world at step **155** to represent the mapping of objects nearer the center of the image being displaced farther away from the viewpoint of the user. The four triangular regions intersect at the new vanishing point P' and form so-called "pyramidic panels" $\mathbf{145'}_{1\text{-}4}$. This is illustrated in FIG. **5**. At step **160**, the corresponding images displayed in regions $\mathbf{145}_{1\text{-}4}$ are then "texture-mapped" onto pyramidic panels $\mathbf{145'}_{1\text{-}4}$, respectively. In this manner, as the viewer moves away from the image's ideal viewing point, IVP, distortions in the image resulting from moving the image's vanishing point from P to P' act to limit the discontinuities between image **115** and the surroundings within CG Part **105**.

In the exemplary illustration of FIG. **5**, distorting image **115** so as to move the vanishing point from P to P' results in pyramidic panel structure forming a four-sided pyramid. Note that its base is fixed and corresponds to original screen or panel **110**, with its peak located at P', which moves in concert with the viewer's current location, V. As the user's viewpoint moves closer to and farther from the image, the image's vanishing point accordingly moves farther from and closer to the user's viewpoint, respectively.

FIGS. **6** through **8** compare the display of two-dimensional image **115** on screen or panel **110** with the display of the same image using the "pyramidic" panels of the present invention. More specifically, FIGS. **6A**, **7A** and **8A** depict viewing two-dimensional image **115** at a location from the left, above, and in front and to the right of the image's ideal viewing point, IVP, respectively, without the use of the present invention. In these latter figures, note that there are discontinuities between the edges of the road and the three-dimensional space of CG Part **105**. FIGS. **6B**, **7B** and **8C** depict the same two-dimensional image distorted

and texture-mapped onto pyramidic panels $145'_{1-4}$, in accordance with the principles of the invention. Note that in these latter figures, the discontinuities in the road edge have been substantially eliminated.

In another embodiment of the present invention, a modified pyramidic panel structure may be used to deal with two-dimensional images containing curved roads, streets, paths and other corridor-like images containing multiple rather than a single vanishing point. In this latter case, screen or panel **110** is segmented using multiple vanishing points to form a so called "articulated pyramidic panel structure." The transformations associated with the articulated pyramidic panel structure dynamically distort different portions of two-dimensional image **115** according to viewer positions so as to adjust the different vanishing points of the image with the viewer's movement. Likewise, as the viewer moves from the image's ideal viewing point, these distortions act to limit the discontinuities between two-dimensional image **115** and the surroundings of CG Part **120**.

FIG. **9** shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image **115** using an articulated pyramidic panel structure. Again, the process is entered at step **170** whenever it is determined that the viewer's position has changed. In general, curve road **125** is treated as two straight corridors placed end-to-end, extending back from screen or panel **110**. Each corridor represents a different portion of road **125** in the three-dimensional space of world **105**, with features nearer the center of the image being farther away from the user's viewpoint.

Using the virtual world's road model of the CG Part **105**, corresponding directional vectors C_1 and C_2 of the corridors are determined at step **175**. Note that portion of the road nearer to the user's viewpoint is represented by C_1, and the portion farther away is represented by C_2. Next, in step **180**, using the vectors C_1 and C_2, the corresponding vanishing points P_1 and P_2 are determined, respectively, for each corridor by projecting those vectors from the image's ideal viewing point, IVP. Alternatively, vanishing points P_1 and P_2 may be determined visually by the user, or by some other suitable means known in the art. In step **185**, using the first corridor's vanishing point, P_1, a first set of pyramidic panels 190_{1-4} are constructed to intersect at vanishing point, P_1, as shown in FIG. **10**.

Now at step **195**, a coupling ratio α is calculated according to the following equation: $\alpha=l/(l+d)$, where 1 is the length of the first corridor, and d is the distance between the image's ideal view point (IVP) and the base of pyramidic panels 190_{1-4}. Each line segment connecting a corner of the base to vanishing point P_1 is then divided into two segments by a point placed according to the coupling ratio, α. More specifically, the length l' of each line segment from the corner of the base of panels 190_{1-4} to this point is given by $l'=\alpha l''$, where l' is the total length of the segment between the corner of the panel and the vanishing point, P_1. These four points labeled Q1 through Q4 are connected to form the base of a second set of smaller pyramidic panels 200_{1-4} embedded within the larger panels (step **205**), as further illustrated in FIG. **10**. The intersection point of pyramidic panels 200_{1-4} is then moved from P_1 to vanishing point, P_2.

For the articulated pyramidic panel structure, the current viewpoint of the user, V, is determined, and a vector $\overline{T}$ projected from the ideal viewing point, IVP, to the viewer's current location, V (step **210**). As the viewer moves, a new vanishing point P'_2 is calculated as $P_2'=P_2+\overline{T}$ at step **215**, and panels 200_{1-4} are then distorted so as to intersect at P'_2. As the viewer move, the four internal points Q1 through Q4 are mapped with the viewer's movement to Q1' through Q4', respectively, in accordance with the following relationship: $Q_i'=Q_i+\alpha\overline{T}$, at step **220**. Note that doing so, accordingly distorts the first set of pyramidic panels 190_{1-4}. At step **225**, the corresponding images in original panels are then texture-mapped into articulated pyramidic panels 190_{1-4} and 200_{1-4}, which have been distorted in accordance with the movement of the viewer. Note that to unambiguously texture-map onto panels 190_{1-4}, these panels are each subdivided into two triangular subregions and then texture-mapped. Shown in FIG. **11** is image **115** seen from a location away from the image's ideal viewing point, using the articulated pyramidic panel structure of the present invention.

Note that the above articulated pyramidic panel structure may also use more than two sets of pyramidic panel structures. Instead of treating the curve road as two straight corridors, multiple corridors may be employed, each placed end-to-end and extending back from screen or panel **110**. Likewise, each corridor represents a different portion of road **125** in the three-dimensional space of world **105**, with features nearer the center of the image being farther away from the user's viewpoint. In such a case, each set of articulated pyramidic panels are formed reiteratively using the above described procedure.

Referring to FIGS. **12–13**, there is shown a third embodiment of the present invention which is similar to that of FIG. **5** and in which "pyramidic panels" $145'_1$, $145'_2$, $145'_3$ and $145'_4$ have been now multi-segmented into sections 205_{1-4}, 210_{1-4}, $205'_{1-4}$, and $210'_{1-4}$, respectively, with the images in original panels 145_{1-4} then texture-mapped into the corresponding translated sections of the pyramidic panel structure, as discussed herein below. It should be recalled that the pyramidic panel structure represents the three-dimensional mapping (x,y,z) of two-dimensional image **115** onto image screen or panel **110** (x,y). Advantageously, the embodiment of FIGS. **12–13** minimizes the depth profile of the pyramidic panel structure along the z-axis. Unlike the embodiment of FIG. **5**, the depth profile of this third embodiment does not substantially vary with changes in the user's viewpoint, V. In the exemplary embodiment of FIG. **5**, recall that distorting image **115** so as to move the vanishing point from P to P' results in the pyramidic panel structure forming a four-sided pyramid. The base of the pyramid is fixed and corresponds to original screen or panel **110**, with its peak located at P' and moves in concert with the viewer's current location, V. As the user's viewpoint moves along the z-axis closer to and farther from two-dimensional image **115**, the image's new vanishing point P' moves farther from and closer to the user's viewpoint, respectively. This latter movement causes the depth profile along the z-axis of the pyramidic panel structure to vary accordingly. Unfortunately, this variation in depth profile can undesirably and/or unexpectedly occlude from the user's view objects in the virtual world, or cause objects to occlude other features in the virtual world inasmuch as the corresponding images in the panels are distorted, as discussed above herein.

To obviate the aforementioned problem, "pyramidic panels" $145'_1$, $145'_2$, $145'_3$ and $145'_4$ have been multi-segmented into sections 205_{1-4}, 210_{1-4}, $205'_{1-4}$, and $210'_{1-4}$ respectively. Each section is then translated along the z-axis to a predetermined distance towards or away from the user's viewpoint, V, but importantly of the same orientation as the original section. For example, segmented sections 205_{1-4} and $205'_{1-4}$ may each have one of its outer edge along the x-axis translated to lie on the x,y plane of screen or panel **110**, as shown in phantom in FIG. **12**. As the user moves to

a new viewpoint, each section in effect pivots about that edge along the x-axis, which edge lies on the surface of panel **110**. Similarly, section 210_{1-4} and $210'_{1-4}$ may each have one of it outer edge along the y-axis lying on the surface of panel **110**. Alternatively, sections 205_{1-4}, and $205'_{1-4}$ may be centered along panel **100**, as depicted in FIG. **14**. Likewise, sections 210_{1-4} and $210'_{1-4}$ may be similarly translated, but for the sake of clarity are not shown in FIGS. **12** and **14**.

Still further, each of sections 205_{1-4} and $205'_{1-4}$ may in effect be rotated or pivoted about its other edge along the x-axis as the user moves to a new viewpoint, V, or, in general, about an axis parallel with an edge along the x-axis of the corresponding section. Again, this latter axis may, but does not have to, lie on the surface of panel **110**. Regardless of the segmenting method chosen, however, translating each section towards or away from the user's viewpoint significantly reduces the depth profile of the pyramidic panel structure along the z-axis, such as depicted in FIG. **12** from, for example, T_2 to T_1.

In still another embodiment of the present invention, sections 205_{1-4} and $205'_{1-4}$ may each be translated a different distance along the z-axis, as illustrated in FIG. **15**. Although not shown, sections 210_{1-4} and $210'_{1-4}$ may likewise be translated. Those skilled in the art will readily understand that doing so advantageously allows the user's viewpoint, V, to extend in front of panel **110** inasmuch as segmented sections corresponding to the image's center may be offset and located closer to the user's viewpoint, V, than the outer sections.

Also, note that segmenting the pyramidic panel structure into a greater number of smaller sections accordingly only further reduces the depth profile, which asymptotically approaches a zero thickness. It is contemplated that the number of sections that the panel structure is divided into may be chosen empirically based on image content as well as the user's range of movement within the virtual world. Preferably, however, the panel structure is dynamically segmented in a reiterative manner. For example, once a user has chosen the maximum desired depth for the panel structure along the z-axis to minimize occlusion, each panel is then reiteratively segmented into a greater number of smaller sections until the depth profile is reduced to the maximum depth profile desired.

In accordance with the principles of the invention, it should be clearly understood, however, that to maintain the apparent integrity of two-dimensional image **115** when texture-mapping the image onto the segmented sections, each segmented sections 205_{1-4}, $205'_{1-4}$, 210_{1-4}, and $210'_{1-4}$ is scaled accordingly with respect to the user's current viewpoint, V, so as to appear to be of the same size as the original corresponding section. This scaling or transform is given by:

$$S_t = S_p \frac{T_t}{T_p}$$

where S_p is the size of the original pyramidic section; S_t is the size of the translated, segmented pyramidic panel section; T_p is distance to the original pyramidic section from the user's viewpoint, V; and T_t is the distance to the translated, segmented pyramidic section. In other words, each segmented, translated section is scaled by the ratio T_t/T_p. Of course, as the user moves within the world, pyramidic panels $145'_{1-4}$ are accordingly re-segmented, translated, and then scaled with respect to the user's new viewpoint, V. Then, the images in original panels 145_{1-4} are again accordingly texture-mapped into the corresponding translated sections 205_{1-4}, $205'_{1-4}$, 210_{1-4}, and $210'_{1-4}$ of the pyramidic panel structure.

The foregoing merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangement which, although not explicitly describe or shown herein, embody the principles of the invention and are included within its spirit and scope.

What is claimed is:

1. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, comprising the steps of:

determining the current viewpoint of the user, V;

dividing the panel into triangular regions;

distorting the triangular regions to form pyramidic panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;

segmenting each of said pyramidic panels into a plurality of sections;

translating each of said plurality of sections of said pyramidic panels towards, or away from, said current viewpoint of the user, V;

texture-mapping the two-dimensional image onto the plurality of sections of the pyramidic panels; and

as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional image and the computer graphics.

2. The invention as defined in claim **1** wherein said segmenting step includes resegmenting said pyramidic panels into a greater number of smaller sections until the depth profile of the pyramidic panel structure formed from said panels reaches a predetermined level.

3. The invention as defined in claim **1** wherein an outer edge of each of said plurality of sections of said pyramidic panels is located on the surface of a predetermined plane.

4. The invention as defined in claim **3** wherein said predetermined plane is the panel onto which the two-dimensional image texture-mapped.

5. The invention as defined in claim **1** wherein the center of each of said plurality of sections of said pyramidic panels is substantially located at the surface of a predetermined plane.

6. The invention as defined in claims **5** wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

7. The invention as defined in claim **1** further comprising scaling each of said plurality of sections of said pyramidic panels in accordance with the following relationship

$$S_t = S_p \frac{T_t}{T_p},$$

where S_p is the size of the section; S_t is the size of the translated section; T_p is distance the section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V.

8. The invention as defined in claim **1** further comprising determining a vector, $\overline{C}$, corresponding to the direction of a portion of a path contained within the two-dimensional

perspective image, and projecting toward the panel the vector, $\overline{C}$, from the image's ideal viewing point, IVP, the intersection of said vector, $\overline{C}$, with the panel being denoted as the image's vanishing point, P.

9. The invention as defined in claim **1** wherein said distorting of the triangular regions in said distorting step includes determining a new vanishing point, P', for said two-dimensional image in accordance with the following relationship $P'=P+\overline{T}$, wherein $\overline{T}$ is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

10. The invention as defined in claim **1** further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

11. The invention as defined in claim **1** wherein said two-dimensional perspective image is a frame of a video.

12. The invention as defined in claim **1** wherein said two-dimensional perspective image is a still picture.

13. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including an object depicted in perspective, said image being such that features of the object closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

- determining a vector, $\overline{C}$, corresponding to the direction of said perspective object in the three-dimensional world;
- projecting towards said panel the vector, $\overline{C}$, from the two-dimensional image's ideal viewing point, IVP, the intersection of said vector, $\overline{C}$, with the panel being denoted as the image's vanishing point, P;
- segmenting said panel into triangular regions intersecting at the image's vanishing point, P;
- determining the current viewpoint, V, of the user and projecting a vector, $\overline{T}$, from the image's ideal viewing point, IVP, to the current viewpoint, V;
- determining a new vanishing point for the two-dimensional image in accordance with the following relationship $P'=P+\overline{T}$;
- distorting the triangular regions in the space of the three-dimensional world such that they intersect at the new vanishing point, P';
- segmenting each of said triangular regions into a plurality of sections;
- translating each of said plurality of sections of said triangular regions towards, or away from, said current viewpoint of the user, V; and
- texture-mapping the two-dimensional image in the triangular regions onto the corresponding sections of said triangular regions.

14. The invention as defined in claim **13** wherein said segmenting step of said triangular regions includes resegmenting said triangular regions into a greater number of smaller sections until the depth profile of the pyramidic panel structure formed from said triangular regions reaches a predetermined level.

15. The invention as defined in claim **13** wherein said predetermined point is substantially near the center of the two-dimensional image.

16. The invention as defined in claim **13** further comprising displaying the texture-mapped two-dimensional image merged with the first portion of said world that is modeled as computer graphics.

17. The invention as defined in claim **13** further comprising the step of calibrating the two-dimensional image as a function of the dimensions of the surroundings within the world.

18. The invention as defined in claim **13** wherein an outer edge of each of said plurality of sections of said triangular regions is located on the surface of a predetermined plane.

19. The invention as defined in claims **18** wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

20. The invention as defined in claim **13** wherein the center of each of said plurality of sections of said triangular regions is located on the surface of a predetermined plane.

21. The invention as defined in claim **20** wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

22. The invention as defined in claim **13** further comprising scaling each of said plurality of sections of said triangular regions in accordance with the following relationship

$$S_t = S_p \frac{T_t}{T_p},$$

where S_p is the size of the section; S_t is the size of the translated section; T_p is distance to the section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V.

23. An apparatus for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second portion of said world is represented by a two-dimensional perspective image, said apparatus comprising:

- means for determining the current viewpoint of the user, V;
- means for dividing the panel into triangular regions;
- as the user moves within the three-dimensional world, means for dynamically distorting the triangular regions to form pyramidic panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;
- means for segmenting each of said pyramidic panels into a plurality of sections;
- means for translating each of said plurality of sections of said pyramidic panels towards, or away from, said current viewpoint of the user, V; and
- means for texture-mapping the two-dimensional image onto the plurality of sections of the pyramidic panels.

24. The invention as defined in claim **23** wherein an outer edge of each of said plurality of sections of said pyramidic panels is located on the surface of a predetermined plane.

25. The invention as defined in claim **24** wherein said predetermined plane is the panel onto which the two-dimensional image is texture-mapped.

26. The invention as defined in claim **23** wherein the center of each of said plurality of sections of said pyramidic panels is located on the surface of a predetermined plane.

27. The invention as defined in claim **23** further comprising means for scaling each of said plurality of sections of said pyramidic panels in accordance with the following relationship

$$S_t = S_p \frac{T_t}{T_p},$$

where S_p is the size of the section; S_t is the size of the translated section; T_p is distance to the original section from the user's viewpoint, V; and T_t is the distance to the translated section from the user's viewpoint, V.

28. The invention as defined in claim 23 further comprising means for determining a vector, $\overline{C}$, corresponding to the direction of a portion of a path contained within the two-dimensional perspective image, and means for projecting toward the panel the vector, $\overline{C}$, from the image's ideal viewing point, IVP, the intersection of said vector, $\overline{C}$, with the panel being denoted as the image's vanishing point, P.

29. The invention as defined in claim 23 wherein said means for distorting the triangular regions includes means for determining a new vanishing point, P', for said two-dimensional image in accordance with the following relationship $P'=P+\overline{T}$, wherein $\overline{T}$ is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

30. The invention as defined in claim 23 further comprising means for calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

31. The invention as defined in claim 23 wherein said two-dimensional perspective image is a frame of a video.

32. The invention as defined in claim 23 wherein said two-dimensional perspective image is a still picture.

* * * * *

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(12) **United States Patent**
Edmark

(10) **Patent No.: US 6,229,548 B1**
(45) **Date of Patent: May 8, 2001**

(54) **DISTORTING A TWO-DIMENSIONAL IMAGE TO REPRESENT A REALISTIC THREE-DIMENSIONAL VIRTUAL REALITY**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

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(51) **Int. Cl.**[7] **G06T 17/00**
(52) **U.S. Cl.** **345/427**
(58) **Field of Search** 345/427, 433, 345/139, 473, 418, 419, 474

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Primary Examiner—Cliff N. Vo
(74) *Attorney, Agent, or Firm*—J. De La Rosa

(57) **ABSTRACT**

A limitation of using two-dimensional images, such as videos or photographs, to represent portions of a three-dimensional world occurs when the user moves within the world and views the world from a location different than from the original context of the two-dimensional image, i.e., from a location different than the image's ideal viewing point (IVP). View changes result in the image not aligning well with the surrounding objects of the three-dimensional world. This limitation is overcome by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and its surroundings.

44 Claims, 8 Drawing Sheets

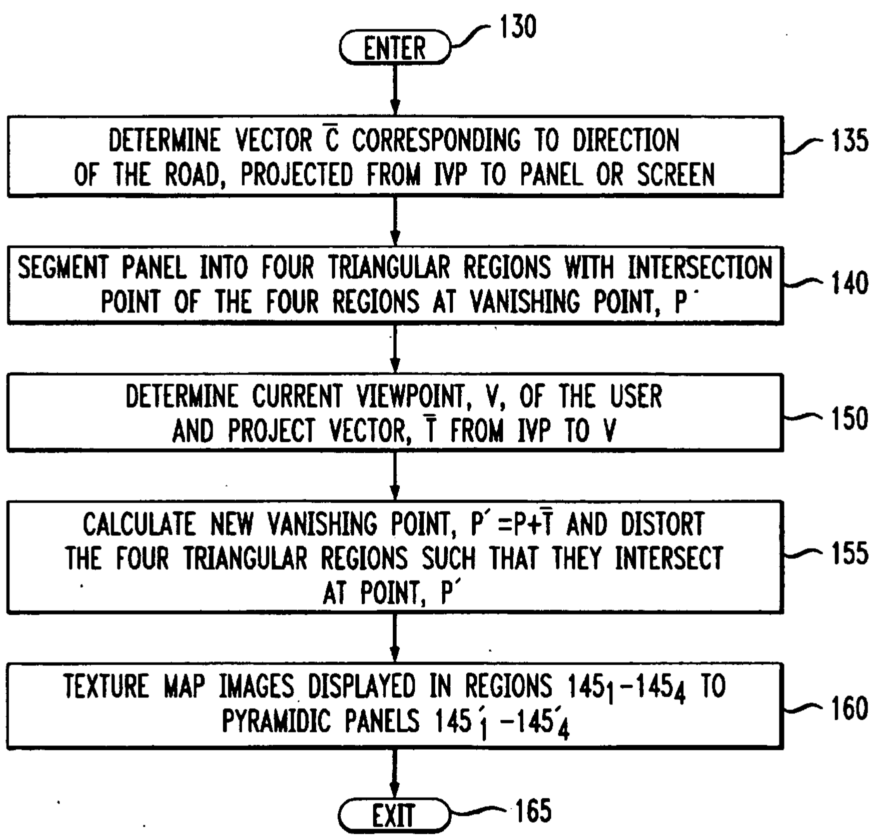


FIG. 1

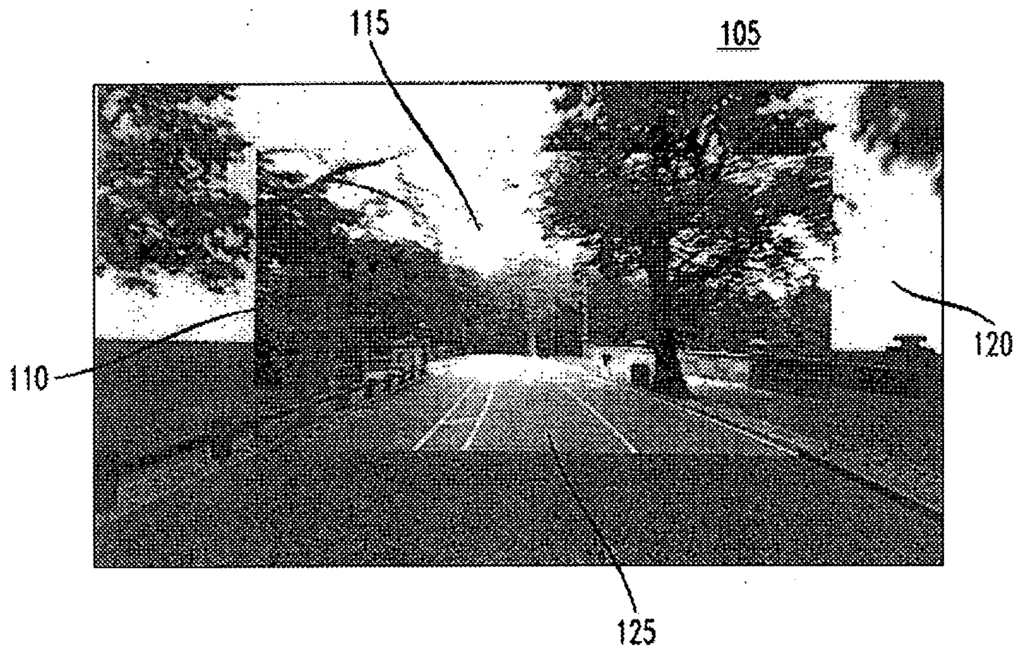


FIG. 2

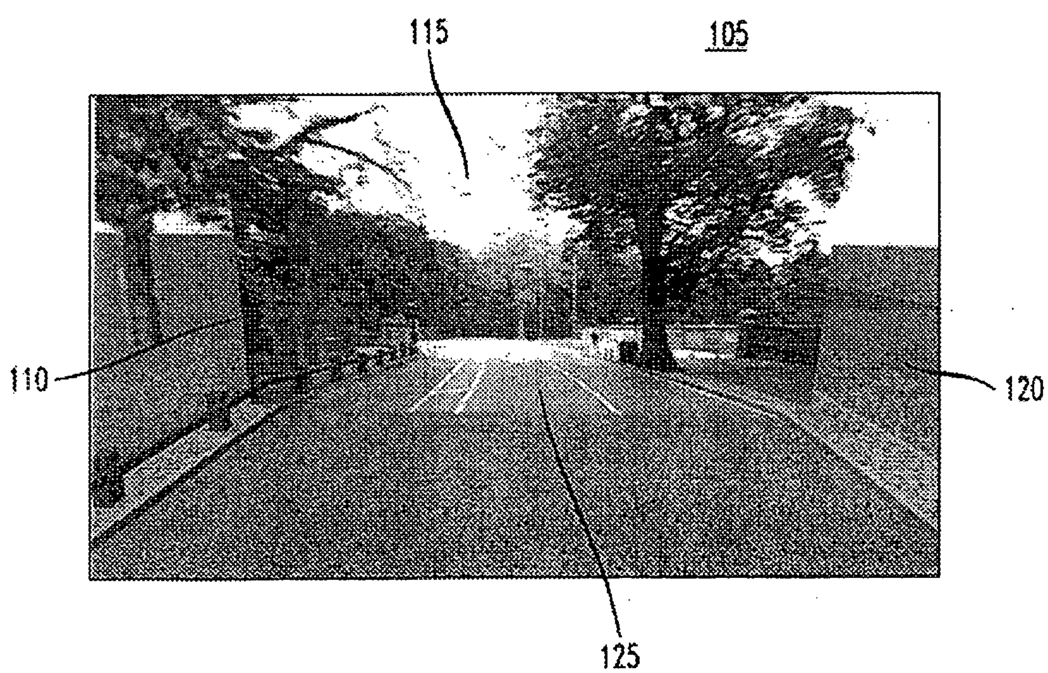


FIG. 3

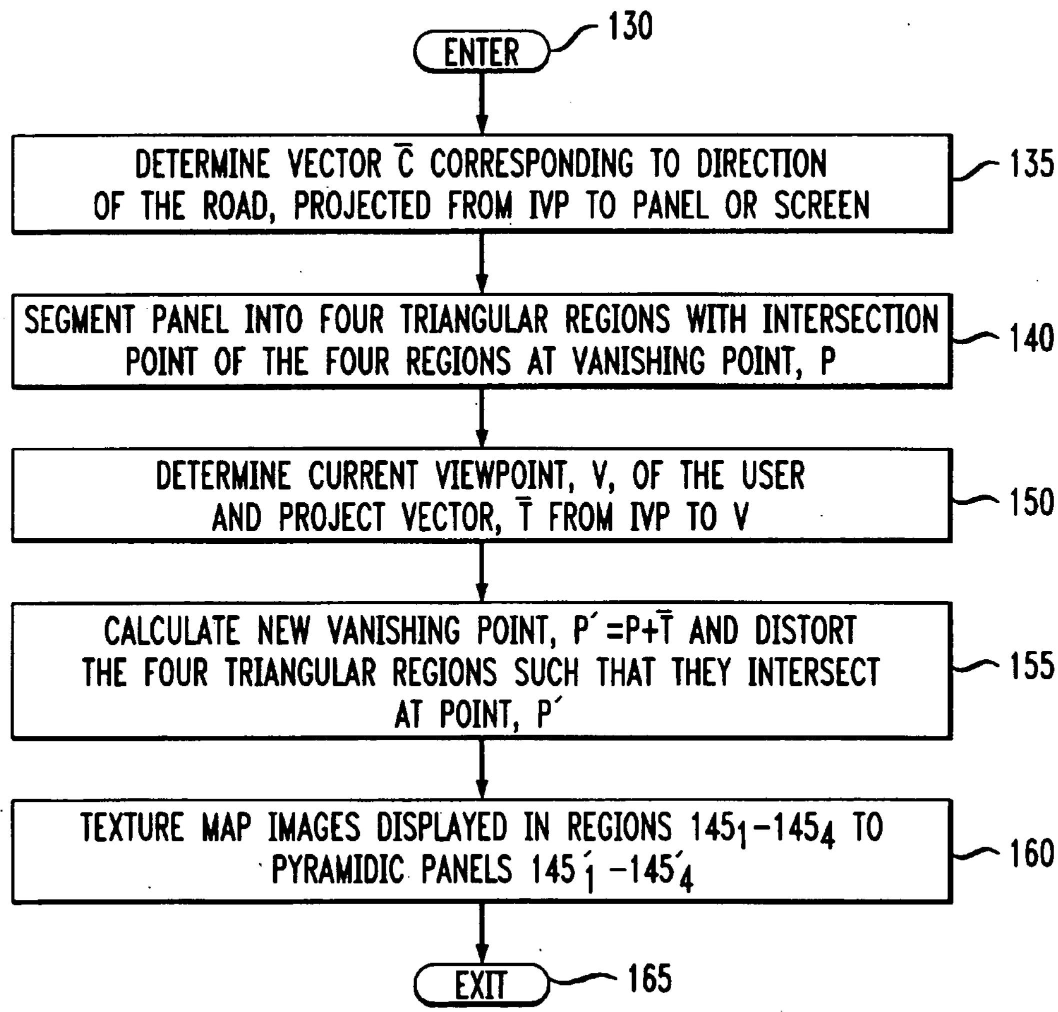
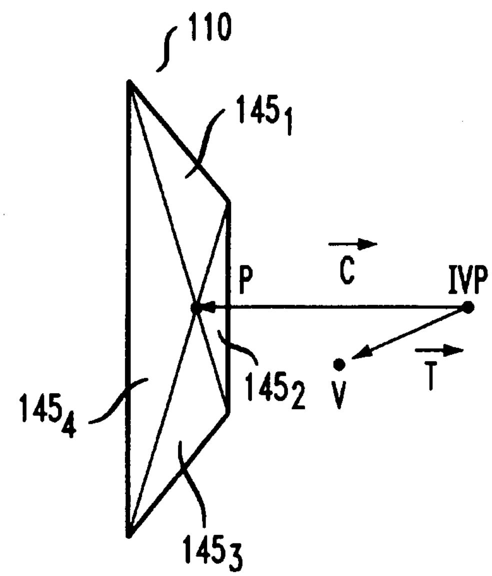
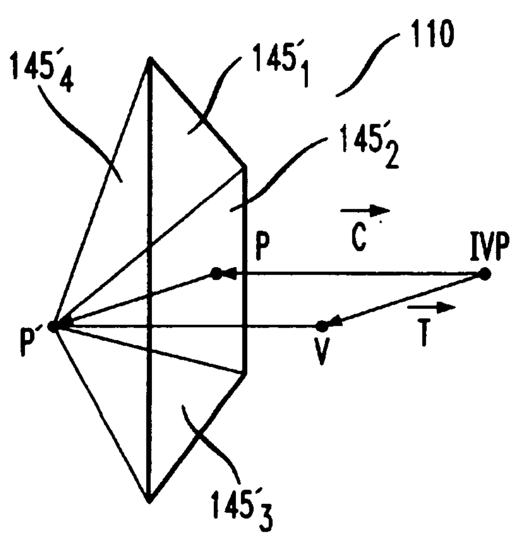

ENTER
130
DETERMINE VECTOR $\bar{C}$ CORRESPONDING TO DIRECTION OF THE ROAD, PROJECTED FROM IVP TO PANEL OR SCREEN
135
SEGMENT PANEL INTO FOUR TRIANGULAR REGIONS WITH INTERSECTION POINT OF THE FOUR REGIONS AT VANISHING POINT, P
140
DETERMINE CURRENT VIEWPOINT, V, OF THE USER AND PROJECT VECTOR, $\bar{T}$ FROM IVP TO V
150
CALCULATE NEW VANISHING POINT, $P' = P + \bar{T}$ AND DISTORT THE FOUR TRIANGULAR REGIONS SUCH THAT THEY INTERSECT AT POINT, P′
155
TEXTURE MAP IMAGES DISPLAYED IN REGIONS 145_1–145_4 TO PYRAMIDIC PANELS $145'_1$–$145'_4$
160
EXIT
165

FIG. 4



110
145_1
P
$\vec{C}$
IVP
145_2
V
$\vec{T}$
145_4
145_3

FIG. 5



$145'_4$
$145'_1$
110
$145'_2$
P
$\vec{C}$
IVP
P'
V
$\vec{T}$
$145'_3$

FIG. 6A

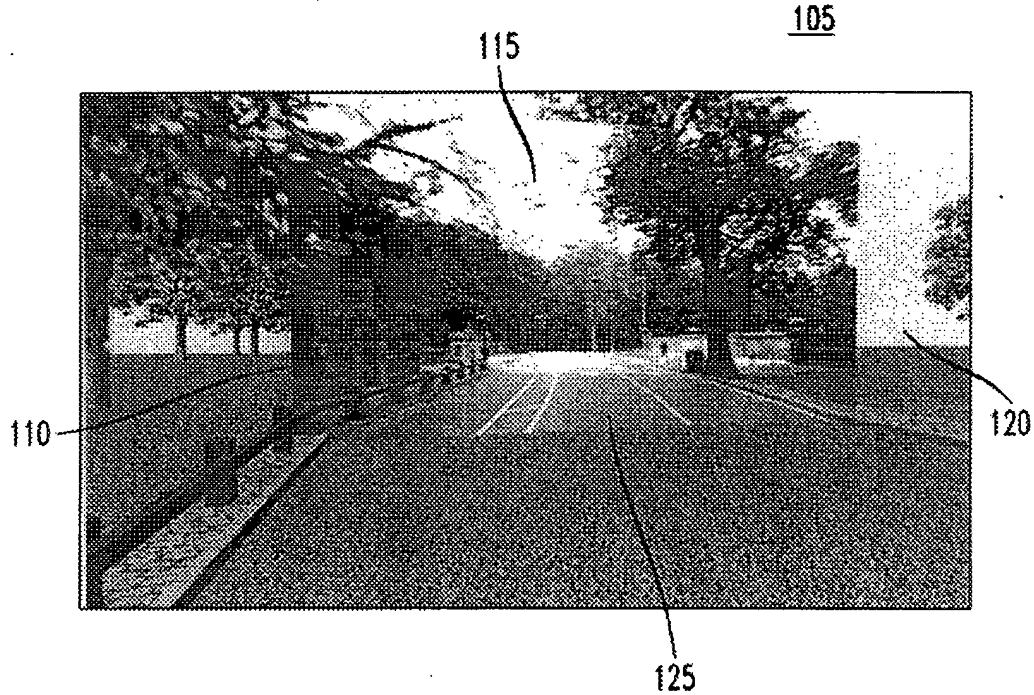


FIG. 6B

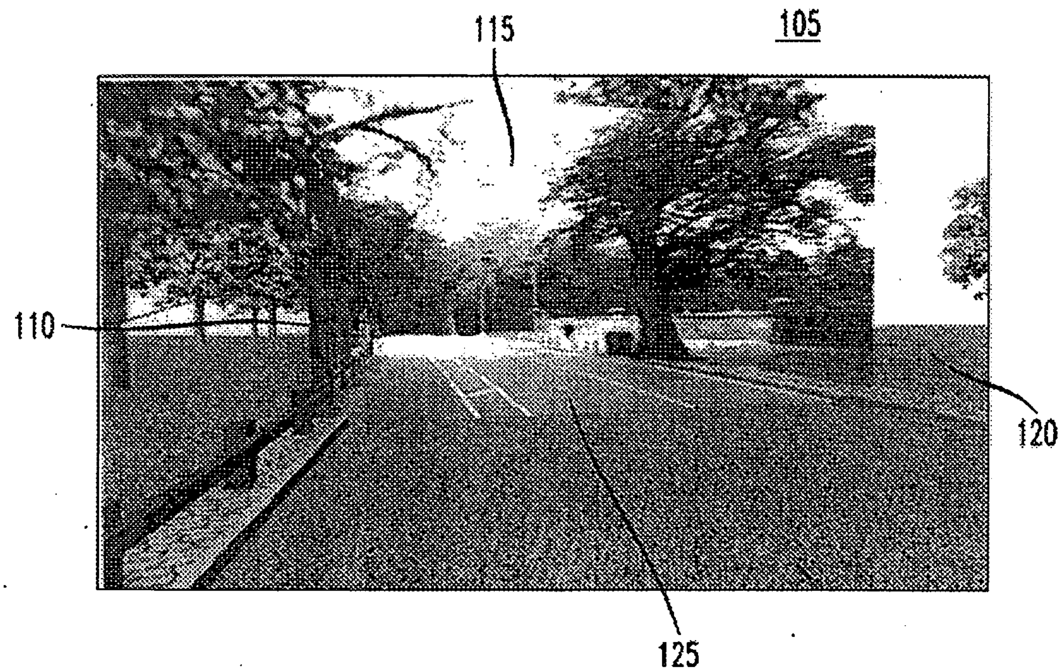


FIG. 7A

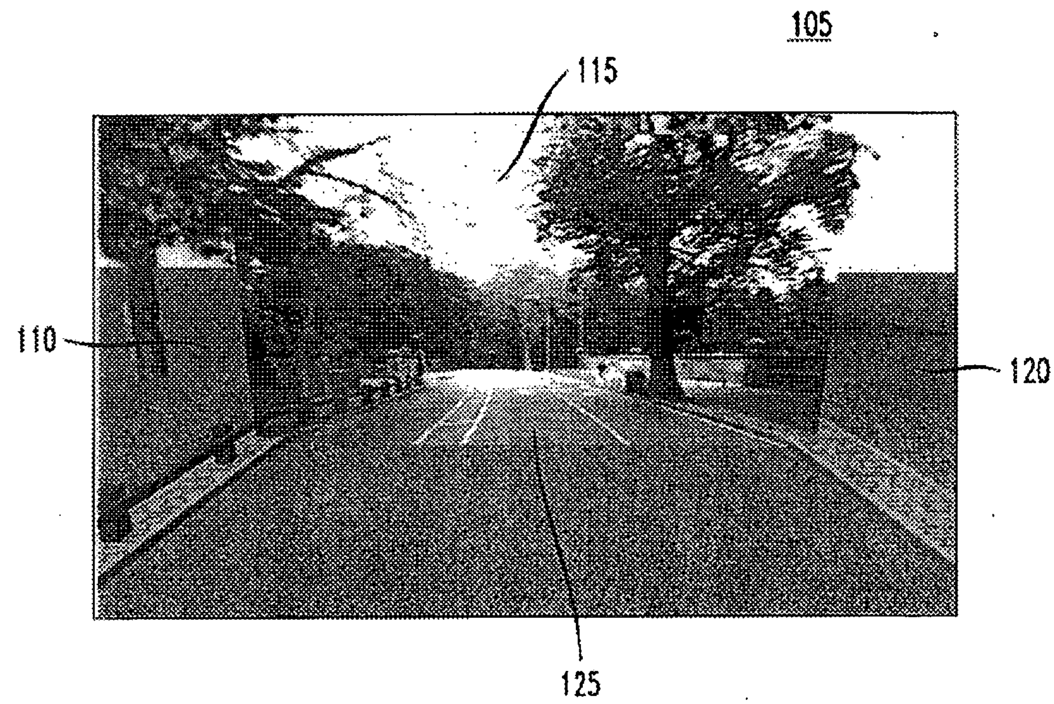


FIG. 7B

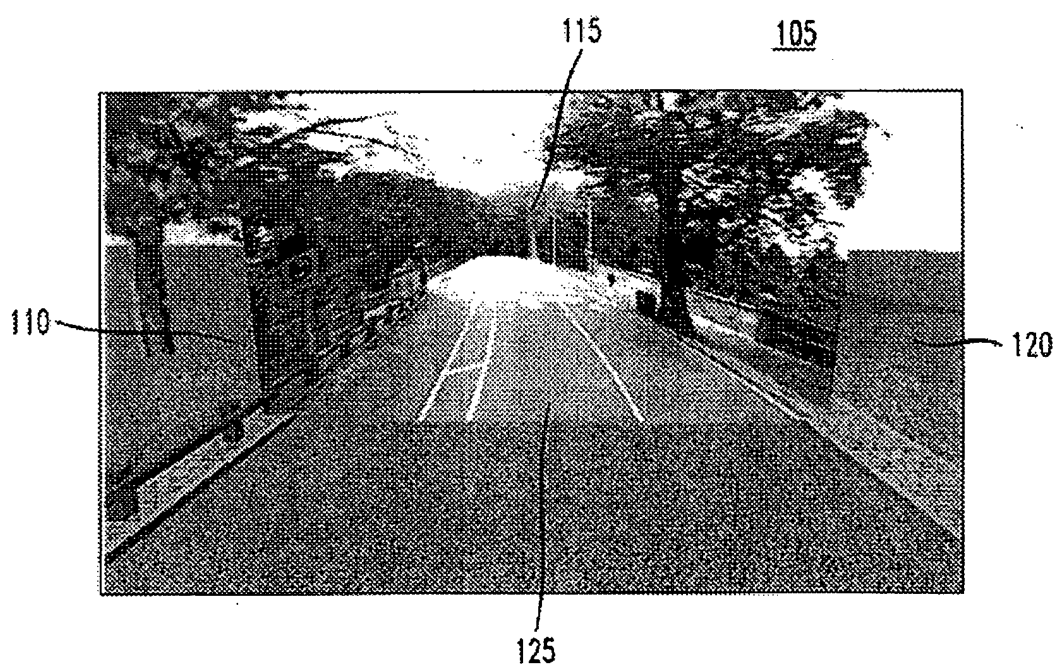


FIG. 8A

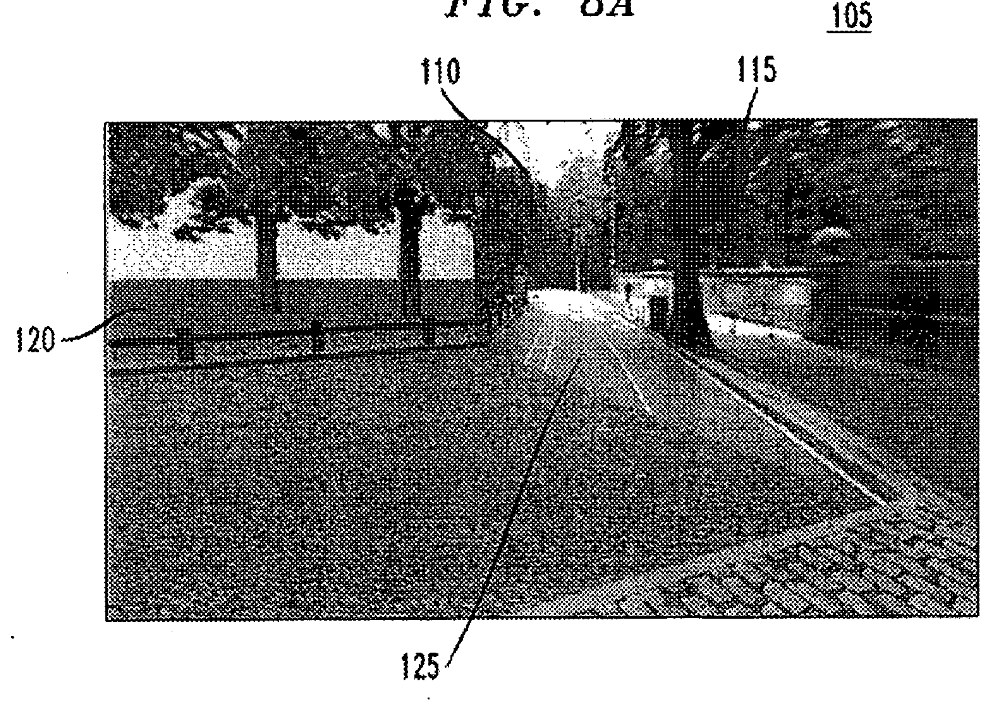


FIG. 8B

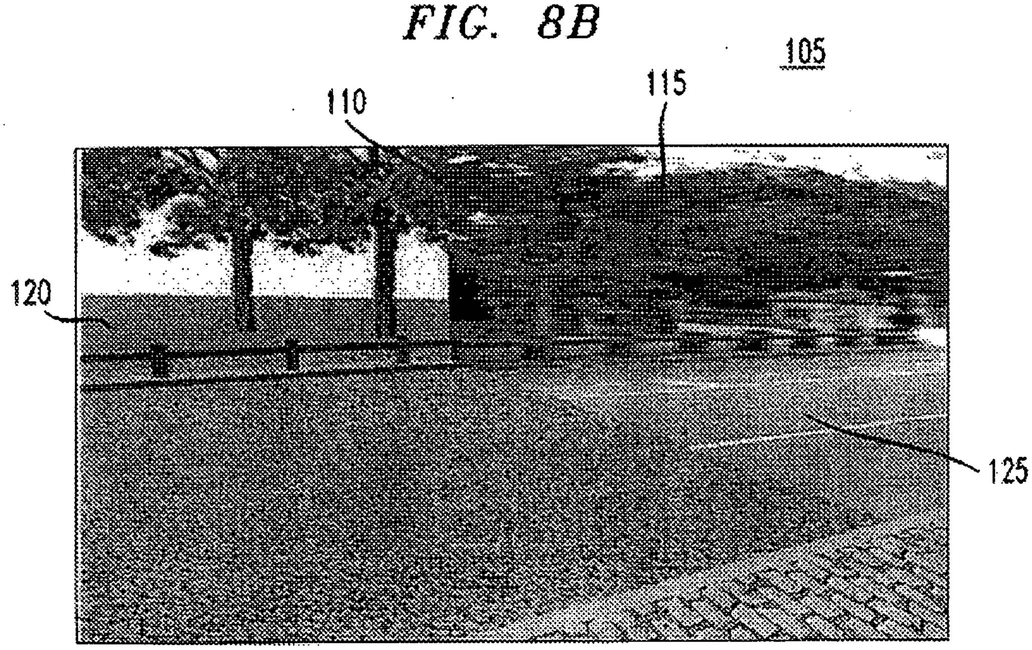


FIG. 9

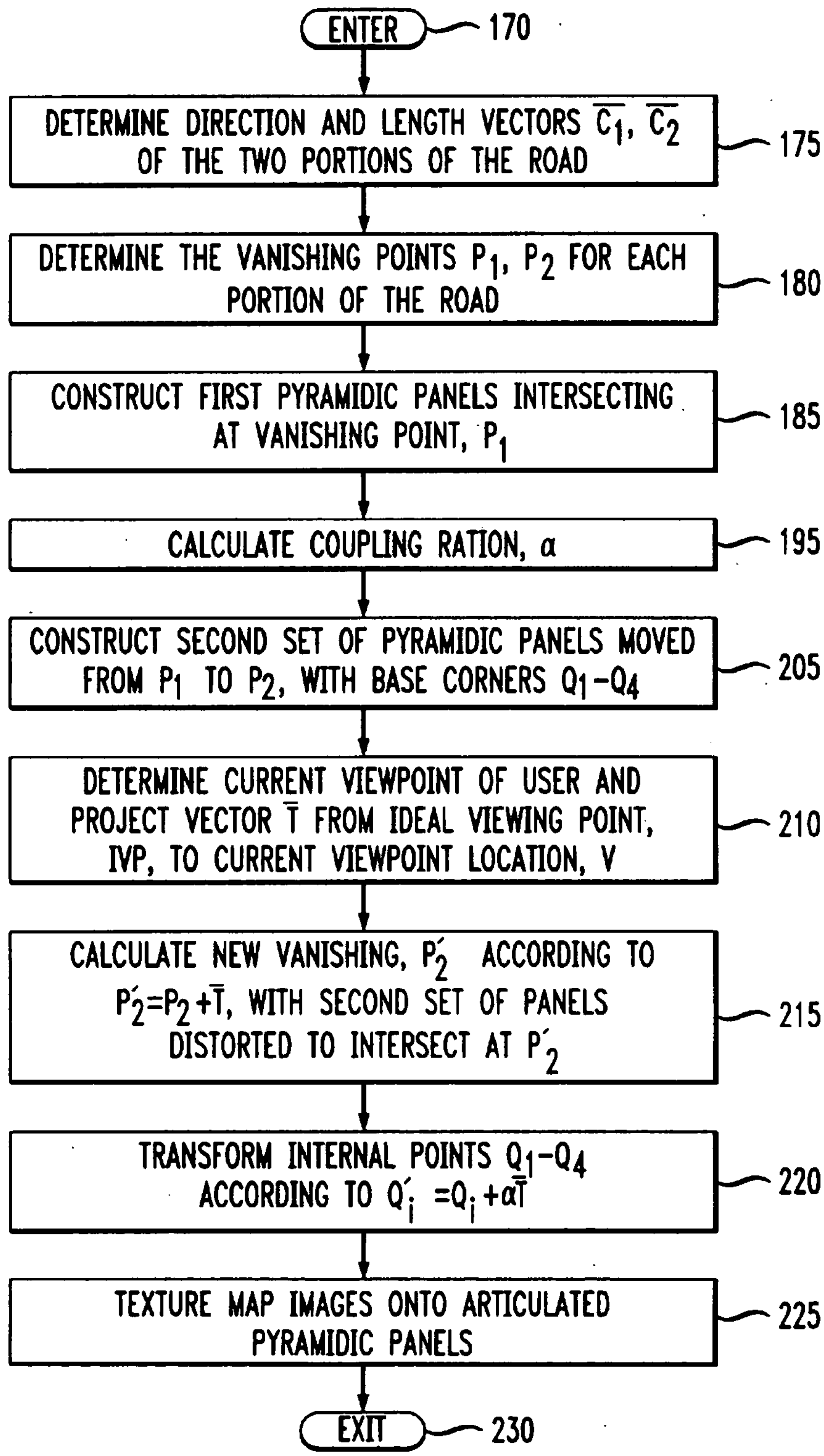

ENTER
170
DETERMINE DIRECTION AND LENGTH VECTORS $\overline{C_1}$, $\overline{C_2}$ OF THE TWO PORTIONS OF THE ROAD
175
DETERMINE THE VANISHING POINTS P_1, P_2 FOR EACH PORTION OF THE ROAD
180
CONSTRUCT FIRST PYRAMIDIC PANELS INTERSECTING AT VANISHING POINT, P_1
185
CALCULATE COUPLING RATION, α
195
CONSTRUCT SECOND SET OF PYRAMIDIC PANELS MOVED FROM P_1 TO P_2, WITH BASE CORNERS Q_1−Q_4
205
DETERMINE CURRENT VIEWPOINT OF USER AND PROJECT VECTOR $\overline{T}$ FROM IDEAL VIEWING POINT, IVP, TO CURRENT VIEWPOINT LOCATION, V
210
CALCULATE NEW VANISHING, P'_2 ACCORDING TO $P'_2=P_2+\overline{T}$, WITH SECOND SET OF PANELS DISTORTED TO INTERSECT AT P'_2
215
TRANSFORM INTERNAL POINTS Q_1−Q_4 ACCORDING TO $Q'_i=Q_i+\alpha\overline{T}$
220
TEXTURE MAP IMAGES ONTO ARTICULATED PYRAMIDIC PANELS
225
EXIT
230

FIG. 10

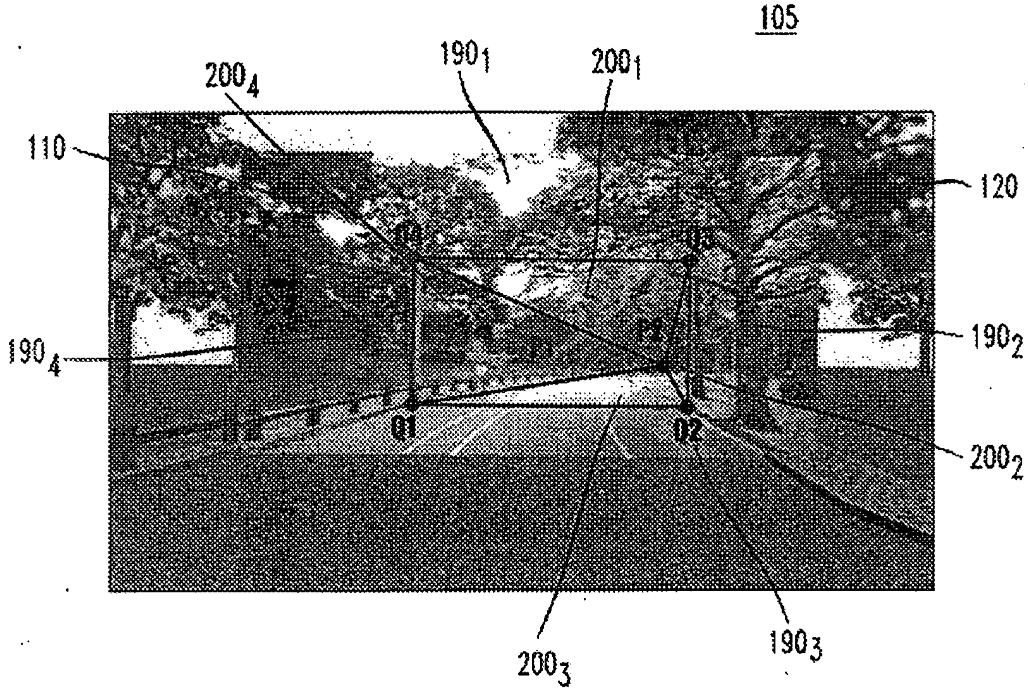
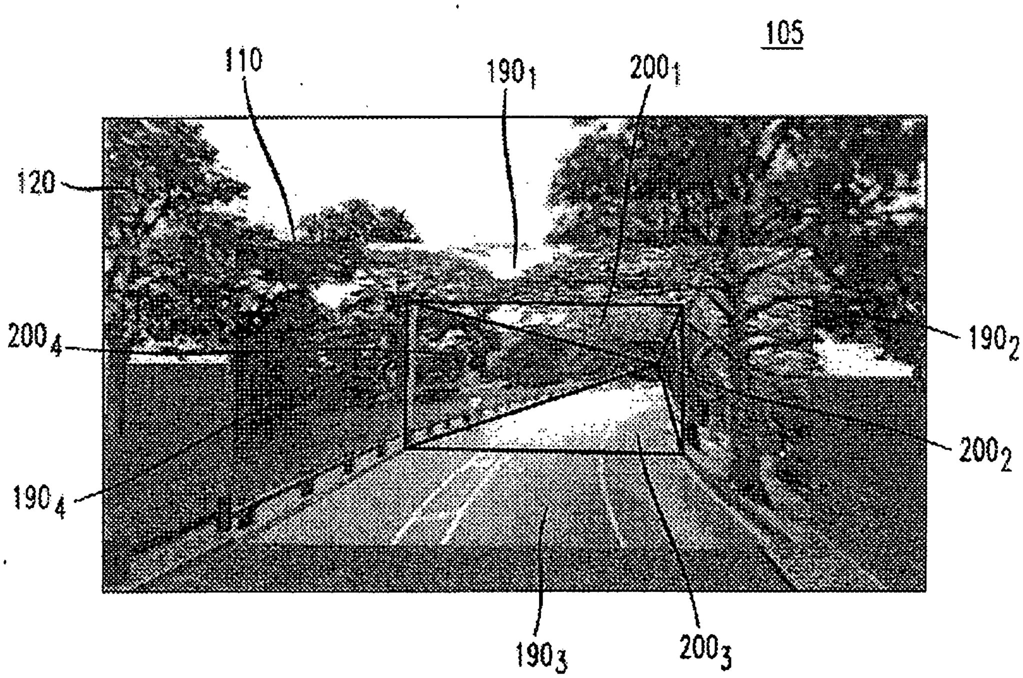

105
190_1
200_1
200_4
110
120
Q4
Q3
P2
190_4
190_2
Q1
Q2
200_2
200_3
190_3

FIG. 11


105
110
190_1
200_1
120
200_4
190_2
200_2
190_4
190_3
200_3

DISTORTING A TWO-DIMENSIONAL IMAGE TO REPRESENT A REALISTIC THREE-DIMENSIONAL VIRTUAL REALITY

TECHNICAL FIELD

This invention relates to the integration of three-dimensional computer graphics and a two-dimensional image to provide a realistic three-dimensional virtual reality experience.

BACKGROUND OF THE INVENTION

The display of a three-dimensional virtual reality world to a user requires considerable computation power, and it is typically costly to develop the necessary highly detailed models required for doing so. In order to simplify the problem, two-dimensional images, such as videos or photographs, may be used to represent or simulate portions of the three-dimensional world. A great reduction in computation power and cost can be achieved by such an arrangement.

SUMMARY OF THE INVENTION

A limitation of such a world occurs when a user moves within the world and views the world from a location different than the original context of a two-dimensional image carefully calibrated to "fit into" the world. View changes, such as from a location different than the image's ideal viewing point, result in the image not aligning or fitting well with the surrounding objects of the three-dimensional world. We have recognized that, in accordance with the principles of the invention, viewpoint changes may be dealt with by distorting the two-dimensional image so as to adjust the image's vanishing point(s) in accordance with the movement of the user. In this manner, as the user moves away from the ideal viewing point, the distortions act to limit the discontinuities between the two-dimensional image and the surroundings of the world.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings:

FIG. **1** shows an example of that which a user sees when a user views the world from the ideal viewing point for a two-dimensional image representing a portion of the world;

FIG. **2** shows an example of that which a user sees when a user moves within the world of FIG. **1** and views the two-dimensional image from a location different than the image's ideal viewing point, without the use of the present invention;

FIG. **3** shows an exemplary process, in accordance with the principles of the invention, for distorting the two-dimensional image using a pyramidic panel structure so as to adjust the image's vanishing point in accordance with the movement of the user;

FIGS. **4** and **5** depict the pyramidic panel structure of the present invention for distorting the two-dimensional image so as to adjust the image's vanishing point, in accordance with the movement of the user;

FIGS. **6A–B** depict examples of that which a user sees when a user views the world from a location left of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. **7A–B** depict examples of that which a user sees when a user views the world from a location above the image's ideal viewing point, without and with the use of the present invention, respectively;

FIGS. **8A–B** depict examples of that which a user sees when a user views the world frôm a location toward the front and the right of the image's ideal viewing point, without and with the use of the present invention, respectively;

FIG. **9** shows an exemplary process, in accordance with the principles of the invention, for distorting a two-dimensional image using an articulated pyramidic panel structure so as to adjust multiple vanishing points in the image, in accordance with the movement of the user;

FIG. **10** depicts an example of the articulated pyramidic panel structure of the present invention; and

FIG. **11** depicts an example of that which a user sees when a user views the world from a location away from the ideal viewing point of the two-dimensional image, with the use of the articulated pyramidic panel structure of the present invention.

DETAILED DESCRIPTION

To better understand the invention, FIGS. **1–2** show examples of that which a user sees when the user moves within a three-dimensional virtual reality world and views a two-dimensional image representing a portion of the world from a location at the image's ideal viewing point (IVP), and then from a different location, i.e., a location different than the original context of the image. It should be understood that the two-dimensional image has been carefully calibrated to "fit into" the surroundings of the world. For simplification of terminology purposes, we shall use the term two-dimensional image to denote either a video clip or a photograph. In accordance with the principles of the invention, as the user moves away from the ideal viewing point, discontinuities between the two-dimensional image and its surroundings are minimized by distorting the image according to the movement of the user.

FIG. **1** shows an exemplary three-dimensional reality world **105**, which is a bicycle path in a park, e.g., Central Park in New York City. In representing world **105**, the present invention exploits a characteristic common to images consisting of views looking down the center of roads, streets or paths, which is that they may be treated as perspective, corridor-like images, with features closer to the center of the image being farther away from the viewer. Accordingly, the bicycle path or road and its immediate vicinity are treated as a kind of three-dimensional, corridor-like image whose floor is formed by the roadbed, whose ceiling is formed by the sky, and whose sidewalls are formed by the roadside objects. In this manner, the principles of a simple point perspective can be used for distorting the landscape image in accordance with the movement of the viewer, as discussed hereinbelow.

World **105** is divided into two portions, screen or panel **110** on which is shown or displayed a two-dimensional image **115**, such as a still photograph, picture, or a current frame of a video clip; and the remainder of the world **120**, which is represented using computer graphics techniques, and is thus referred to herein as computer graphics (CG Part)

120. Within CG Part **120** there are various synthetic, three-dimensional landscapes or objects modeled in, for example, the Virtual Reality Modeling Language (VRML). Two-dimensional image **115** simulates landscape or terrain portions of the world **105**, here a virtual road or course **125** for walking, running or pedaling a bicycle.

Note that although three-dimensional world **105** cannot be actually rendered in a two-dimensional plane, it can be projected to and displayed on a two-dimensional plane so as to appear to have three dimensions. Accordingly, the techniques of the present invention are preferably employed with computers and software, which are sufficiently sophisticated to display images on a two-dimensional plane as having three dimensions. Note also that to make the world look realistic, computer graphics display techniques use the z component of objects to scale accordingly the x and y components as a function of its distance to the user's viewpoint.

Two-dimensional image **115** is carefully placed, cropped and sized to achieve continuity with the surrounding environment of the CG Part **120**. Note that the image is clipped so that the left and right edges of the road in CG Part **120** pass through the left and right bottom comers of the road, respectively, in image **115**. This clipping ensures that the roadbed maps to the floor of the hypothetical corridor. In so doing, portions at the boundary between two-dimensional image **115** and CG part **120** are co-planar, i.e., at the same distance away from the user's viewpoint. In "fitting" two-dimensional image **115** to CG part **120**, however, there exits only one viewpoint from which that image's content properly corresponds to the surrounding environment of CG Part **120**. This unique location is called the image's ideal viewing point (IVP). In FIG. **1**, two-dimensional image **115** is seen from its ideal viewing point, and from this view, image **115** aligns well with the surrounding objects of CG Part **120**.

Users, however, rarely view image **115** only from its idea viewing point. As the user moves within world **105**, such as left or right of road **125**, as they round curves, or move closer to or farther from the image, they see image **115** from positions other than its ideal viewing point. Absent the use of the present invention, such viewpoint changes would cause objects or features within image **115** to align improperly with the surrounding environment, as further illustrated in FIG. 2.

In accordance with the principles of the invention, however, screen or panel **110** uses a display structure called a "pyramidic panel structure" for displaying two-dimensional image **115** within the surrounding three-dimensional space of the CG Part **105** so as to deal with viewpoint changes. The transformations associated with the pyramidic panel structure dynamically distort two-dimensional image **115** according to viewer's position so as to adjust the image's vanishing point with the viewer's movement. As the viewer moves from the image's ideal viewing point, these distortions act to limit discontinuities between image **115** and the surroundings of CG Part **120**.

FIG. **3** shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image **115** so as to adjust its vanishing point in accordance with the viewer's position. The process is entered at step **130** whenever it is determined that the viewer's position has changed.

Using the virtual world's road model of the CG Part **105**, a vector, $\overline{C}$, corresponding to the direction of road **125** is projected at step **135** from the image's ideal viewing point, IVP, to panel or screen **110** on which is displayed image **115**. Note that the panel is two-dimensional, but represents three-dimensional space with objects nearer the center of the image being farther away from the plane of the viewer. The panel structure is shown in FIG. **4**. The point of intersection with screen or panel **110** is the image's vanishing point, P. Note, however, that the vanishing point may be set visually by the user, if desired, or by other suitable computer graphics processing techniques known in the art. Next, in step **140**, screen or panel **110** is segmented into four triangular regions $\mathbf{145_{1\text{-}4}}$, one for each of the regions bordering CG Part **120**, with the intersection point of the four regions located at the vanishing point, P.

Thereafter in step **150**, the current viewpoint of the user, V, is determined, and a vector $\overline{T}$ projected from the ideal viewing point, IVP, to the viewer's current location, V. In accordance with the principles of the invention, as the viewer moves, a new vanishing point P' is calculated as $P'=P+\overline{T}$. The four triangular regions $\mathbf{145_{1\text{-}4}}$ are distorted in the three-dimensional space of the virtual world at step **155** to represent the mapping of objects nearer the center of the image being displaced farther away from the viewpoint of the user. The four triangular regions intersect at the new vanishing point P' and form so-called "pyramidic panels" $\mathbf{145'_{1\text{-}4}}$. This is illustrated in FIG. **5**. At step **160**, the corresponding images displayed in regions $\mathbf{145_{1\text{-}4}}$ are then "texture-mapped" onto pyramidic panels $\mathbf{145'_{1\text{-}4}}$, respectively. In this manner, as the viewer moves away from the image's ideal viewing point, IVP, distortions in the image resulting from moving the image's vanishing point from P to P' act to limit the discontinuities between image **115** and the surroundings within CG Part **105**.

In the exemplary illustration of FIG. **5**, distorting image **115** so as to move the vanishing point from P to P' results in pyramidic panel structure forming a four-sided pyramid. Note that its base is fixed and corresponds to original screen or panel **110**, with its peak located at P', which moves in concert with the viewer's current location, V. As the user's viewpoint moves closer to and farther from the image, the image's vanishing point accordingly moves farther from and closer to the user's viewpoint, respectively.

FIGS. **6** through **8** compare the display of two-dimensional image **115** on screen or panel **110** with the display of the same image using the "pyramidic" panels of the present invention. More specifically, FIGS. **6A**, **7A** and **8A** depict viewing two-dimensional image **115** at a location from the left, above, and in front and to the right of the image's ideal viewing point, IVP, respectively, without the use of the present invention. In these latter Figures, note that there are discontinuities between the edges of the road and the three-dimensional space of CG Part **105**. FIGS. **6B**, **7B** and **8C** depict the same two-dimensional image distorted and texture-mapped onto pyramidic panels $\mathbf{145'_{1\text{-}4}}$, in accordance with the principles of the invention. Note that in these latter figures, the discontinuities in the road edge have been substantially eliminated.

In another embodiment of the present invention, a modified pyramidic panel structure may be used to deal with

two-dimensional images containing curved roads, streets, paths and other corridor-like images containing multiple rather than a single vanishing point. In this latter case, screen or panel **110** is segmented using multiple vanishing points to form a so called "articulated pyramidic panel structure." The transformations associated with the articulated pyramidic panel structure dynamically distort different portions of two-dimensional image **115** according to viewer positions so as to adjust the different vanishing points of the image with the viewer's movement. Likewise, as the viewer moves from the image's ideal viewing point, these distortions act to limit the discontinuities between two-dimensional image **115** and the surroundings of CG Part **120**.

FIG. **9** shows an exemplary process in accordance with the principles of the invention for distorting two-dimensional image **115** using an articulated pyramidic panel structure. Again, the process is entered at step **170** whenever it is determined that the viewer's position has changed. In general, curve road **125** is treated as two straight corridors placed end-to-end, extending back from screen or panel **110**. Each corridor represents a different portion of road **125** in the three-dimensional space of world **105**, with features nearer the center of the image being farther away from the user's viewpoint.

Using the virtual world's road model of the CG Part **105**, corresponding directional vectors C_1 and C_2 of the corridors are determined at step **175**. Note that portion of the road nearer to the user's viewpoint is represented by C_1, and the portion farther away is represented by C_2. Next, in step **180**, using the vectors C_1 and C_2, the corresponding vanishing points P_1 and P_2 are determined, respectively, for each corridor by projecting those vectors from the image's ideal viewing point, IVP. Alternatively, vanishing points P_1 and P_2 may be determined visually by the user, or by some other suitable means known in the art. In step **185**, using the first corridor's vanishing point, P_1, a first set of pyramidic panels $\mathbf{190}_{1\text{-}4}$ are constructed to intersect at vanishing point, P_1, as shown in FIG. **10**.

Now at step **195**, a coupling ratio a is calculated according to the following equation: $\alpha=l(l+d)$, where l is the length of the first corridor, and d is the distance between the image's ideal view point (IVP) and the base of pyramidic panels $\mathbf{190}_{1\text{-}4}$. Each line segment connecting a corner of the base to vanishing point P_1 is then divided into two segments by a point placed according to the coupling ratio, α. More specifically, the length l' of each line segment from the corner of the base of panels $\mathbf{190}_{1\text{-}4}$ to this point is given by $l'=\alpha l''$, where l" is the total length of the segment between the corner of the panel and the vanishing point, P_1. These four points labeled Q1 through Q4 are connected to form the base of a second set of smaller pyramidic panels $\mathbf{200}_{1\text{-}4}$ embedded within the larger panels (step **205**), as further illustrated in FIG. **10**. The intersection point of pyramidic panels $\mathbf{200}_{1\text{-}4}$ is then moved from P_1 to vanishing point, P_2.

For the articulated pyramidic panel structure, the current viewpoint of the user, V, is determined, and a vector $\overline{T}$ projected from the ideal viewing point, IVP, to the viewer's current location, V (step **210**). As the viewer moves, a new vanishing point P'_2 is calculated as $P'_2=P_2+\overline{T}$ at step **215**, and panels $\mathbf{200}_{1\text{-}4}$ are then distorted so as to intersect at P'_2. As the viewer move, the four internal points Q1 through Q4 are mapped with the viewer's movement to Q1' through Q4', respectively, in accordance with the following relationship: $Q'_i=Q_i+\alpha\overline{T}$, at step **220**. Note that doing so, accordingly distorts the first set of pyramidic panels $\mathbf{190}_{1\text{-}4}$. At step **225**, the corresponding images in original panels are then texture-mapped into articulated pyramidic panels $\mathbf{190}_{1\text{-}4}$ and $\mathbf{200}_{1\text{-}4}$, which have been distorted in accordance with the movement of the viewer. Note that to unambiguously texture-map onto panels $\mathbf{190}_{1\text{-}4}$, these panels are each subdivided into two triangular subregions and then texture-mapped. Shown in FIG. **11** is image **115** seen from a location away from the image's ideal viewing point, using the articulated pyramidic panel structure of the present invention.

Note that the above articulated pyramidic panel structure may also use more than two sets of pyramidic panel structures. Instead of treating the curve road as two straight corridors, multiple corridors may be employed, each placed end-to-end and extending back from screen or panel **110**. Likewise, each corridor represents a different portion of road **125** in the three-dimensional space of world **105**, with features nearer the center of the image being farther away from the user's viewpoint. In such a case, each set of articulated pyramidic panels are formed reitererately using the above described procedure.

The foregoing merely illustrates the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangement which, although not explicitly describe or shown herein, embody the principles of the invention and are included within its spirit and scope.

What is claimed is:

1. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, comprising the steps of:

determining the current user's viewpoint of the two-dimensional perspective image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give a portion of the two-dimensional perspective image a vanishing point;

distorting the two-dimensional perspective image so as to move the vanishing point of said portion of the two-dimensional perspective image according to the current user's viewpoint; and

as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional perspective image and the computer graphics.

2. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, comprising the steps of:

determining the current user's viewpoint of the two-dimensional perspective image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give a portion of the two-dimensional perspective image a vanishing point; and

distorting the portions of the two-dimensional perspective image so as to adjust the corresponding vanishing point

of each of said of said portion according to the current user's viewpoint.

3. The invention as defined in claim 1 further comprising displaying the distorted two-dimensional perspective image merged with the first portion of said world that is modeled as computer graphics.

4. The invention as defined in claim 1 wherein said two-dimensional perspective image is a frame of a video.

5. The invention as defined in claim 1 wherein said two-dimensional perspective image is a still picture.

6. The invention as defined in claim 1 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

7. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, comprising the steps of:

determining the current user's viewpoint of the two-dimensional perspective image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give different portions of the two-dimensional perspective image vanishing points;

distorting different portions of the two-dimensional perspective image so as to adjust the corresponding vanishing point of each of said portions according to the current user's viewpoints and

as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional perspective image and the computer graphics.

8. The invention as defined in claim 7 wherein said predetermined point is substantially near the center of the two-dimensional image.

9. The invention as defined in claim 7 further comprising displaying the distorted two-dimensional perspective image merged with the first portion of said world that is modeled as computer graphics.

10. The invention as defined in claim 7 wherein said two-dimensional perspective image is a frame of a video.

11. The invention as defined in claim 7 wherein said two-dimensional image perspective is a still picture.

12. The invention as defined in claim 7 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

13. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image, comprising the step of:

distorting the two-dimensional image, in which features closer to a predetermined point of the image are farther away from a user's viewpoint, so as to adjust a corresponding vanishing point of a portion of said two-dimensional image as a function of the current viewpoint of a user; and as the user moves within the three-dimensional world, repeating the above step so as to limit discontinuities between the two-dimensional image and the computer graphics.

14. The invention as defined in claim 13 wherein said predetermined point is substantially near the center of the two-dimensional image.

15. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel, comprising the steps of:

determining the current viewpoint of the user, V;

dividing the panel into triangular regions;

distorting the triangular regions to form pyramidic panels such that a corresponding vanishing point, P, of a portion of the two-dimensional image moves as a function of the current viewpoint of the user;

texture-mapping the two-dimensional image onto the pyramidic panels; and

as the user moves within the three-dimensional world, repeating the above steps so as to limit discontinuities between the two-dimensional image and the computer graphics.

16. The invention as defined in claim 15 further comprising determining a vector, $\overline{C}$, corresponding to the direction of a portion of a path contained within the two-dimensional perspective image, and projecting toward the panel the vector, $\overline{C}$, from the image's ideal viewing point, IVP, the intersection of said vector, $\overline{C}$, with the panel being denoted as the image's vanishing point, P.

17. The invention as defined in claim 15 wherein said distorting of the triangular regions in said distorting step includes determining a new vanishing point, P', for said two-dimensional image in accordance with the following relationship $P'=P+\overline{T}$, wherein $\overline{T}$ is a vector from the image's ideal viewing point, IVP, to the current viewpoint, V.

18. The invention as defined in claim 15 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

19. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel comprising the steps of:

determining the current viewpoint of the user;

dividing the panel into different regions corresponding to different portions of the two-dimensional image, said image being such that features closer to a predetermined point of the image are farther away from the user's viewpoint so as to give different portions of the two-dimensional image different vanishing points;

distorting the different regions of the panel to form articulated pyramidic panels such that the corresponding vanishing points of different portions of the two-dimensional image move as a function of the current viewpoint of the user;

texture-mapping the two-dimensional image onto the articulated pyramidic panels; and

as the user moves within the three-dimensional world, repeating the above step so as to limit discontinuities between the two-dimensional image and the computer graphics.

20. The invention as defined in claim 19 wherein said predetermined point is substantially near the center of the two-dimensional image.

21. The invention as defined in claim 19 wherein said two-dimensional perspective image is a frame of a video.

22. The invention as defined in claim 19 wherein said two-dimensional perspective image is a still picture.

23. The invention as defined in claim 19 further comprising the step of calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

24. The invention as defined in claim 19 wherein said first and second portions of the two-dimensional image include portions of a road with dissimilar directions.

25. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including an object depicted in perspective, said image being such that features of the object closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

determining a vector, $\overline{C}$, corresponding to the direction of said perspective object in the three-dimensional world;

projecting towards said panel the vector, $\overline{C}$, from the two-dimensional image's ideal viewing point, IVP, the intersection of said vector, $\overline{C}$, with the panel being denoted as the image's vanishing point, P;

segmenting said panel into triangular regions intersecting at the image's vanishing point, P;

determining the current viewpoint, V, of the user and projecting a vector, $\overline{T}$, from the image's ideal viewing point, IVP, to the current viewpoint, V;

determining a new vanishing point for the two-dimensional image in accordance with the following relationship $P'=P+\overline{T}$;

distorting the triangular regions in the space of the three-dimensional world such that they intersect at the new vanishing point, P's and

texture-mapping the two-dimensional image in the triangular regions onto said distorted triangular regions.

26. The invention as defined in claim 25 wherein said predetermined point is substantially near the center of the two-dimensional image.

27. The invention as defined in claim 25 further comprising displaying the texture-mapped two-dimensional image merged with the first portion of said world that is modeled as computer graphics.

28. The invention as defined in claim 25 further comprising the step of calibrating the two-dimensional image as a function of the dimensions of the surroundings within the world.

29. A method for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional image texture-mapped on a panel, said two-dimensional image including a path depicted in perspective wherein features of the path closer to a predetermined point of the image are farther away from a user's viewpoint, comprising the steps of:

dividing said path into first and second portions;

determining vectors $\overline{C_1}$ and $\overline{C_2}$ corresponding to the direction and length of said first and second portions, respectively;

projecting towards said panel the vectors $\overline{C_1}$ and $\overline{C_2}$ from the two-dimensional image's ideal viewing point, IVP, the intersection of said vectors $\overline{C_1}$ and $\overline{C_2}$ with the panel being denoted as the image's vanishing points, P_1 and P_2, respectively;

segmenting said panel into a first set of four triangular regions intersecting at the image's vanishing point, P_1;

determining a coupling ratio α given by $\alpha=l/(l+d)$, where l is the length of the vector $\overline{C_1}$, and d is the distance between the image's ideal viewing point, IVP, and the panel;

dividing each of the four line segments of the first set of four triangular regions connecting to a corner of the panel and labeling those points Q1 through Q4 with the exterior forming a first set of articulated pyramidic panels;

segmenting the regions interior to the points Q1 through Q4 into a second set of four triangular regions intersecting at vanishing point P_2;

moving the intersection point of the first set of the four triangular regions from P_1 to P_2;

determining the current viewpoint, V, of the user and projecting a vector, $\overline{T}$, from the image's ideal viewing point, IVP, to the current viewpoint, V;

determining a new vanishing point for the second portion of the two-dimensional image in accordance with the following relationships,

$$P'_2=P_2+\overline{T};$$

distorting the second set of four triangular regions in the three-dimensional space of the world such that they intersect at the new vanishing point, P'_2 thereby forming a second set of articulated pyramidic panels;

mapping the points Q1 through Q4 to Q1' through Q4', respectively, according with the following relationship, $Q'_{i-Qi}+\alpha\overline{T}$, where I an integer between 1 through 4; and

texture-mapping the corresponding first and second portions of the two-dimensional image in the first and second sets of triangular regions onto the first and second sets of articulated pyramidic panels, respectively.

30. The invention as defined in claim 29 wherein said predetermined point is substantially near the center of the two-dimensional image.

31. The invention as defined in claim 29 further comprising displaying the texture-mapped two-dimensional image merged with the first portion of said world that is modeled as computer graphics.

32. The invention as defined in claim 29 further comprising the step of calibrating the two-dimensional image as a function of the dimensions of the surroundings within the world.

33. An apparatus for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, said apparatus comprising:

means for determining the current user's viewpoint of the two-dimensional perspective image, said perspective image being such that features of a perspective object closer to a predetermined point of the image are farther away from a user's viewpoint so as to give the perspective object a vanishing point; and

as the user moves within the three-dimensional world, means for repeatingly distorting the two-dimensional perspective image so as to adjust the corresponding vanishing point of the perspective object within said image according to the current user's view point.

34. The invention as defined in claim **33** wherein said predetermined point is substantially near the center of the two-dimensional image.

35. The invention as defined in claim **33** further comprising means for displaying the distorted two-dimensional perspective image with the first portion of said world that is modeled as computer graphics.

36. The invention as defined in claim **33** wherein said two-dimensional perspective image is a frame of video.

37. The invention as defined in claim **33** wherein said two-dimensional perspective image is still a picture.

38. The invention as defined in claim **33** further comprising means for calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

39. An apparatus for use in processing a view of a three-dimensional world in which a first portion of said world is modeled as computer graphics and a second non-computer modeled portion of said world is represented by a two-dimensional perspective image, said apparatus comprising;

means for determining the user's current viewpoint of the two-dimensional perspective image, said two-dimensional perspective image being such that features closer to a predetermined point of the image are farther away from a user's viewpoint so as to give different portions of the two-dimensional perspective image each a vanishing point; and

as the user moves within the three dimensional world, means for repeatingly distorting portions of the two-dimensional perspective image so as to adjust the corresponding vanishing points of different portions of the two-dimensional image according to the current user's viewpoint.

40. The invention as defined in claim **39** wherein said predetermined point is substantially near the center of the two-dimensional image.

41. The invention as defined in claim **39** further comprising means for displaying the distorted two-dimensional perspective image merged with the first portion of said world that is modeled as computer graphics.

42. The invention as defined in claim **39** wherein said two-dimensional perspective image is a frame of a video.

43. The invention as defined in claim **39** wherein said two-dimensional perspective image is a still picture.

44. The invention as defined in claim **39** further comprising means for calibrating the two-dimensional perspective image as a function of the dimensions of the surroundings within the world.

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(54) METHOD AND APPARATUS FOR ADJUSTING AN IMAGE TO COMPENSATE FOR AN OFFSET POSITION OF A USER

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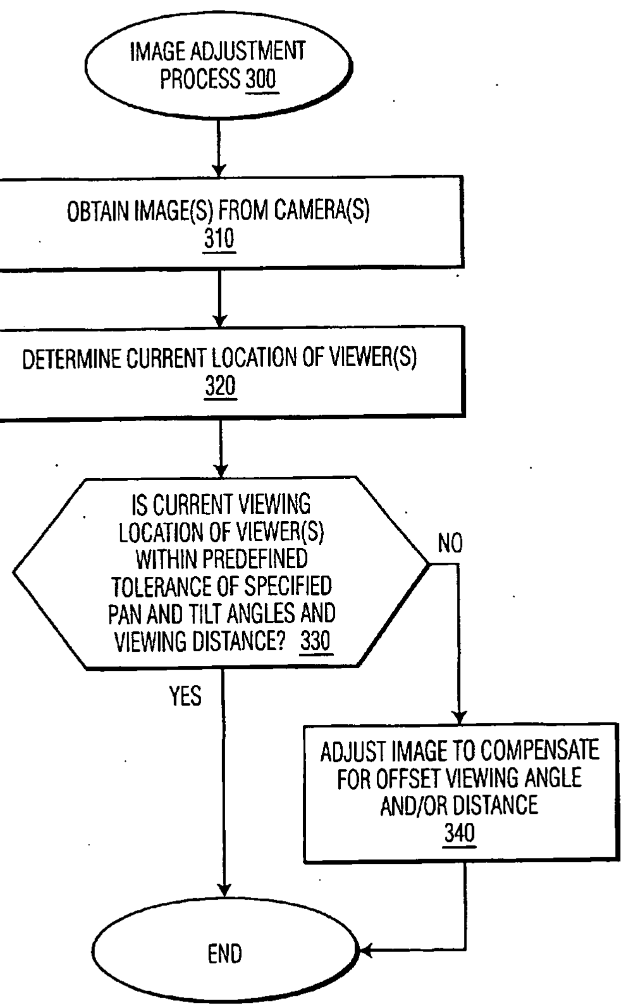
(57) **ABSTRACT**

A method and apparatus are disclosed for monitoring the location of one or more viewer(s) and dynamically adjusting the image to compensate for the current location of the viewer(s). The image is adjusted to compensate for a viewing location (pan angle, Θ, tilt angle, Φ, or distance, d) outside of a specified range of values. The input image is adjusted so that the output image appears as originally intended, for the current viewing location of the viewer. A linear transformation technique is applied to the original image to generate a modified image. The linear transformation maps the pixels in the original image to a new space that distorts the image, such that when the modified image is viewed from an offset viewing location the image appears as if being viewed from a direct viewing location.



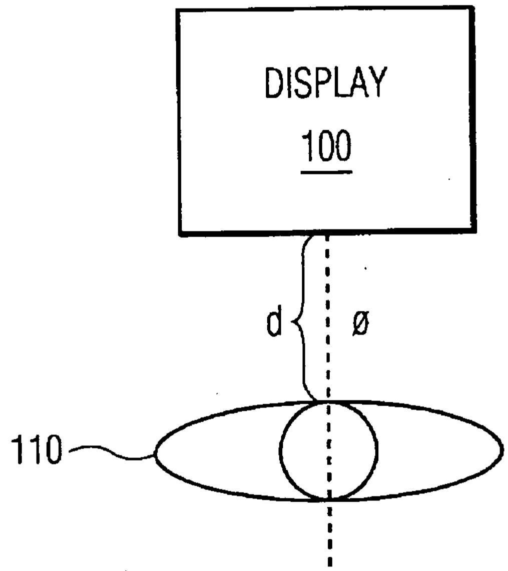


FIG. 1A

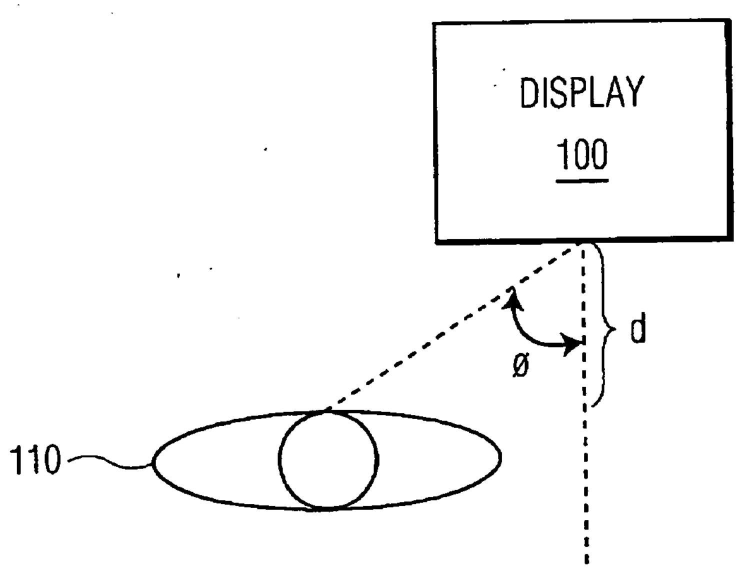
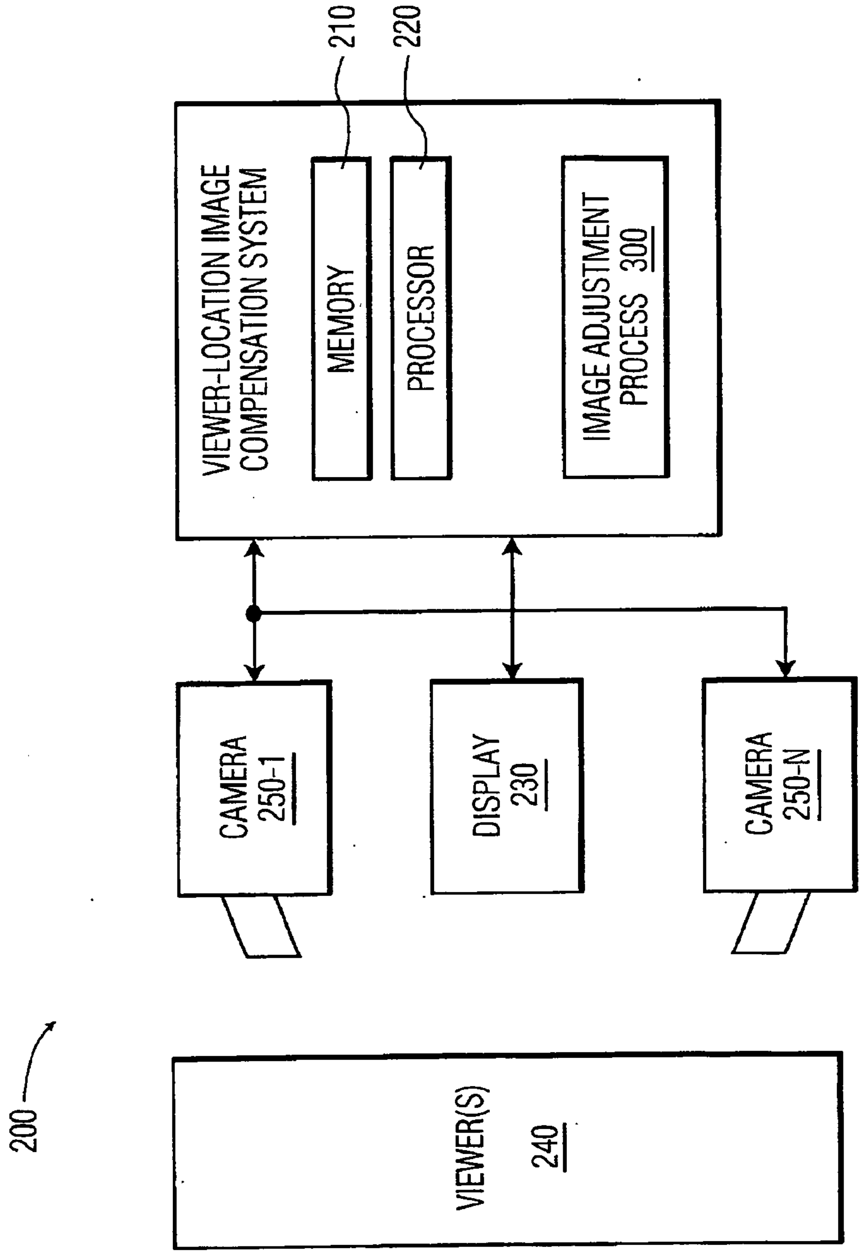


FIG. 1B



210
220
VIEWER-LOCATION IMAGE COMPENSATION SYSTEM
MEMORY
PROCESSOR
IMAGE ADJUSTMENT PROCESS 300
CAMERA 250-1
DISPLAY 230
CAMERA 250-N
200
VIEWER(S) 240

FIG. 2

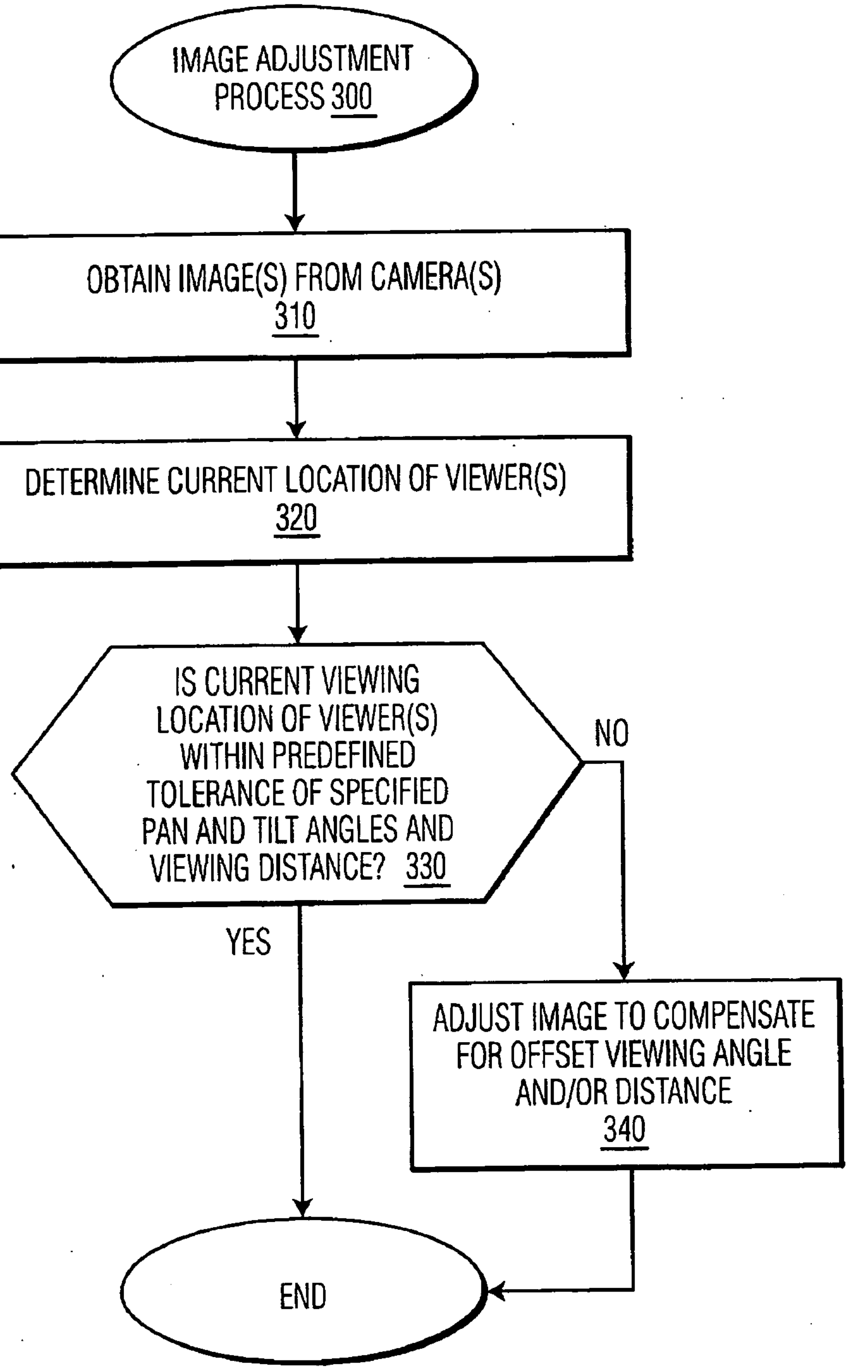


IMAGE ADJUSTMENT PROCESS 300
OBTAIN IMAGE(S) FROM CAMERA(S) 310
DETERMINE CURRENT LOCATION OF VIEWER(S) 320
IS CURRENT VIEWING LOCATION OF VIEWER(S) WITHIN PREDEFINED TOLERANCE OF SPECIFIED PAN AND TILT ANGLES AND VIEWING DISTANCE? 330
NO
YES
ADJUST IMAGE TO COMPENSATE FOR OFFSET VIEWING ANGLE AND/OR DISTANCE 340
END

FIG. 3

METHOD AND APPARATUS FOR ADJUSTING AN IMAGE TO COMPENSATE FOR AN OFFSET POSITION OF A USER

FIELD OF THE INVENTION

[0001] The present invention relates to methods and apparatus for controlling a display, and more particularly, to a method and apparatus for automatically adjusting an image to compensate for an offset viewing location of a user.

BACKGROUND OF THE INVENTION

[0002] The consumer marketplace offers a wide variety of devices for displaying images, such as televisions, portable DVD players and computer monitors. Most advances in display technology have been directed to techniques for reducing glare and reflection resulting from light sources and objects located in the vicinity of the display. Typically, image quality is improved by employing polarizing panels or screen coatings (or both) to reduce glare and reflections.

[0003] **FIG. 1A** illustrates a display **100** that is observed by a viewer **110** from a viewing location defined by a pan angle, Θ, tilt angle, Φ (not shown), and distance, d, relative to the display **100**. Display devices are typically optimized for direct viewing by the viewer from a specified viewing distance. In the example of **FIG. 1A**, the viewer **110** is observing the display **100** from a distance, d, with a direct viewing angle where the pan and tilt angles, Θ and Φ, are approximately zero degrees.

[0004] If the viewer **110** is observing the display **100** from a pan angle, Θ, or tilt angle, Φ, (or both) that is offset from the intended direct viewing angle of the display **100**, as shown in **FIG. 1B**, then the image will appear distorted to the viewer **110**. Generally, if the viewer **110** is observing the display **100** from a pan angle, Θ, or tilt angle, Φ, (or both) that is offset from a predefined viewing angle of the display then the portions of the displayed image appearing on the opposite side of the image relative to the viewing location will appear smaller than when viewed from the intended direct viewing angle.

[0005] Similarly, if the viewer **110** is observing the display **100** from a distance, d, that is outside of the optimized viewing range of the display, then the image will likewise appear distorted to the viewer **110**. Generally, if the viewer **110** is observing the display from a distance, d, beyond the optimized viewing range of the display **100**, then the image will appear smaller to the viewer **110** than when viewed from the intended viewing range. It is further noted that as the size of the display area increases, the distortion caused by viewing the image from an offset position is more significant.

[0006] A need therefore exists for a method and apparatus for adjusting an image to compensate for an offset position of a viewer. A further need exists for a method and apparatus for adjusting an image to compensate for a viewing distance that is outside of an optimized viewing range of a display.

SUMMARY OF THE INVENTION

[0007] Generally, a method and apparatus are disclosed for monitoring the location of one or more viewer(s) and dynamically adjusting the image to compensate for the current location of the viewer(s). In particular, the image is adjusted to compensate for a viewing location (pan angle, Θ, tilt angle, Φ, or distance, d) outside of a specified range of values. The present invention employs image processing techniques to adjust the input image so that the output image appears as originally intended, for the current viewing location of the viewer.

[0008] According to one aspect of the invention, the disclosed viewer-location image compensation system morphs an image to compensate for an offset pan angle, Θ, or tilt angle, Φ, (or both) to compress portions of the image nearest the viewer and enlarge portions of the image further from the viewer. Likewise, the disclosed viewer-location image compensation system scales an image to compensate for a viewing distance, d, outside of an optimized viewing range of a display ($d<d_{min}$ or $d>d_{max}$).

[0009] In order to compensate for an offset viewing location, the original image can be adjusted using a linear transformation technique to generate a modified image. Generally, the linear transformation maps the pixels in the original image to a new space that distorts the image, such that when the modified image is viewed from an offset viewing location the image appears as if being viewed from a direct viewing location.

[0010] A more complete understanding of the present invention, as well as further features and advantages of the present invention, will be obtained by reference to the following detailed description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] **FIG. 1A** is a top view illustrating a viewer observing a display from a direct viewing angle;

[0012] **FIG. 1B** is a top view illustrating a viewer observing a display from an offset viewing angle;

[0013] **FIG. 2** is a schematic block diagram of a viewer-location image compensation system in accordance with the present invention; and

[0014] **FIG. 3** is a flow chart describing an exemplary image adjustment process embodying principles of the present invention.

DETAILED DESCRIPTION

[0015] **FIG. 1** illustrates a viewer-location image compensation system **200** in accordance with the present invention. As shown in **FIG. 2**, the viewer-location image compensation system **200** includes one or more cameras **250-1** through **250-N** (hereinafter, collectively referred to as cameras **250**) that are focused on one or more viewer(s) **240** of a display **230**. The images generated by the cameras **250** are utilized to derive the viewing location of a viewer **240** (pan angle, Θ, tilt angle, Φ, and distance, d). The display **230** is any type of image or video display suitable for presenting images to the viewer **240** or for otherwise interacting with a human user, including liquid crystal displays (LCDs), projection systems and displays based on cathode-ray tube technology.

[0016] Generally, the viewer-location image compensation system **200** optimizes the image for the current location of a single viewer **240** or an average location of all viewers **240** in accordance with the present invention. The present invention optimizes an image for an offset viewing location

of a viewer **240**, where one or more of the pan angle, Θ, tilt angle, Φ, or distance, d, are outside a specified range of values. In this manner, the present invention employs image processing techniques to adjust the input image so that the output image appears as originally intended, for the current viewing location of the viewer **240**.

[0017] According to one feature of the present invention, the viewer-location image compensation system **200** adjusts an image to compensate for an offset viewing angle of a viewer. In particular, as discussed further below in conjunction with **FIG. 3**, the viewer-location image compensation system **200** morphs an image to compensate for an offset viewing pan angle, Θ, or tilt angle, Φ, to compress portions of the image nearest the viewer **240** and enlarge portions of the image further from the viewer **240**. In this manner, the viewer-location image compensation system **200** allows an image viewed from an offset viewing angle ($\Theta \neq 0$ or $\Phi \neq 0$) to appear as if the image is viewed from a direct viewing angle (Θ and Φ approximately equal to 0).

[0018] According to another feature of the present invention, the viewer-location image compensation system **200** adjusts an image to compensate for a viewing distance, d, outside of an optimized viewing range of a display **230**. In particular, as discussed further below in conjunction with **FIG. 3**, the viewer-location image compensation system **200** changes the size of an image to compensate for a viewing location, d, outside of an optimized viewing range of a display **230** ($d<d_{min}$ or $d>d_{max}$).

[0019] Thus, if the current viewing distance, d, is greater than the optimized region ($d>d_{max}$), then the image is enlarged. Likewise, if the current viewing distance, d, is less than the optimized region ($d<d_{min}$), then the image is reduced. For example, the viewer-location image compensation system **200** can scale the image size to compensate for a viewing distance outside of the optimized viewing region. In an image having textual portions, for example, the size or thickness (or both) of the text can be adjusted. In this manner, the viewer-location image compensation system **200** allows an image viewed from a viewing distance, d, outside of an optimized viewing range of a display **230** to appear as if the image is viewed from a viewing distance, d, within the optimized viewing range of a display **230**.

[0020] Each camera **250** may be embodied, for example, as a fixed or pan-tilt-zoom (PTZ) camera for capturing image or video information. The image information generated by the camera(s) **250** are processed by the viewer-location image compensation system **200**, in a manner discussed below in conjunction with **FIG. 3**, to determine the viewing location of a viewer **240**. It is noted that a one-camera system can estimate the viewing distance, d, based on the size of the person appearing in the image (assuming a standard size person).

[0021] The viewer-location image compensation system **200** may be embodied as any computing device, such as a personal computer or workstation, that contains a processor **220**, such as a central processing unit (CPU), and memory **210**, such as RAM and/or ROM. Alternatively, the viewer-location image compensation system **200** may be embodied as an application specific integrated circuit (ASIC) (not shown) that is included, for example, in a television, set-top terminal or another electronic device.

[0022] Memory **210** configures the processor **220** to implement the methods, steps, and functions disclosed herein. As shown in **FIG. 2**, the viewer-location image compensation system **200** includes an image adjustment process **300** that is implemented by the processor **220**. Generally, the exemplary image adjustment process **300** monitors the location of one or more viewer(s) **240** and dynamically adjusts the image to compensate for the current location of the viewer(s) **240** in accordance with the present invention. The image adjustment process **300** can optimize an image for the current viewing location (pan angle, Θ, tilt angle, Φ, and distance, d) of a viewer **240**.

[0023] The memory **210** could be distributed or local and the processor **220** could be distributed or singular. The memory **210** could be implemented as an electrical, magnetic or optical memory, or any combination of these or other types of storage devices. Moreover, the term "memory" should be construed broadly enough to encompass any information able to be read from or written to an address in the addressable space accessed by processor **220**. With this definition, information on a network is still within memory **210** because the processor **220** can retrieve the information from the network. It should be noted that each distributed processor that makes up processor **220** generally contains its own addressable memory space.

[0024] **FIG. 3** is a flow chart describing an exemplary image adjustment process **300**. As previously indicated, the image adjustment process **300** monitors the location of one or more viewer(s) **240** and dynamically adjusts the image to compensate for the current location of the viewer(s) **240** in accordance with the present invention. The image adjustment process **300** may be executed continuously, intermittently or upon a detected movement of a viewer **240**, as would be apparent to a person of ordinary skill in the art.

[0025] As shown in **FIG. 3**, the image adjustment process **300** initially obtains one or more images from the camera(s) **250** during step **310**. Thereafter, the image adjustment process **300** determines the location of any viewer(s) **240** that are present during step **320**. A test is performed during step **330** to determine if the current viewing location of the viewer(s) **240** is within a predefined tolerance of specified values for each of the pan angle, Θ, tilt angle, Φ, and distance, d.

[0026] If it is determined during step **330** that the current viewing location of the viewer(s) **240** is not within a predefined tolerance of a specified viewing location, then the image is adjusted during step **340** to compensate for the offset viewing angle or distance. An exemplary technique for adjusting the image to compensate for the offset viewing location of the viewer is described below in a section entitled "Image Adjustment Technique."

[0027] If, however, it is determined during step **330** that the current viewing location of the viewer(s) **240** is within a predefined tolerance of a specified viewing location, then program control terminates.

Image Adjustment Technique

[0028] The original image can be expressed as a two-by-two matrix of pixels. In order to compensate for an offset viewing location, the original image is adjusted in an exemplary embodiment of the present invention using a linear transformation technique. Generally, the linear transformation maps the pixels in the original image, I, to a new space

to generate a modified image, M, that distorts the image, such that when the modified image is viewed from an offset viewing location the image appears as if being viewed from a direct viewing location. Thus, a given pixel in the original image can be expressed as P_I and a given pixel in the modified image can be expressed as P_M.

[0029] As previously indicated, the current viewing location is the current location of the viewer's eye, P_e, and is fully defined by the pan angle, Θ, tilt angle, Φ, and distance, d, relative to a fixed point on the display. the current location of the viewer's eye, P_e, can also be expressed as follows:

$$P_e = R\begin{bmatrix}0\\0\\d\end{bmatrix}$$

$$\text{where } R = \begin{bmatrix}\cos\Theta & 0 & -\sin\Theta\\ \sin\Phi\cos\Theta & \cos\Phi & \sin\Phi\cos\Theta\\ \cos\Phi\sin\Theta & -\sin\Phi & \cos\Phi\cos\Theta\end{bmatrix}$$

[0030] In a first embodiment, it is assumed that the user is far away from the display. The distance from the display can thus be ignored. Thus, each pixel in the modified image, P_M, can be obtained by identifying the appropriate index of a corresponding pixel in the original image, P_I. Thus, to obtain a pixel value in the modified image, the appropriate index of the corresponding pixel in the original image, P_I, is identified as follows:

$$P_I = R\cdot P_M = R\begin{bmatrix}x_0\\y_0\\0\end{bmatrix}.$$

[0031] Since this embodiment ignores the distance from the display, the corresponding pixel in the original image, P_I, can be expressed as follows

$$P_I = \begin{pmatrix}x_i\\y_i\end{pmatrix}.$$

[0032] In a second embodiment, the distance, d, of the user from the display is considered. Thus, to obtain a pixel value in the modified image, the appropriate index of the corresponding pixel in the original image, P_I, is identified as follows:

$$P_I = R\left(P_M - \frac{\langle P_M, P_e\rangle(P_M - P_e)}{\langle P_e - P_M, P_e\rangle}\right).$$

$$\text{where } P_M = \begin{bmatrix}x_0\\y_0\\0\end{bmatrix}.$$

[0033] It is noted that in both the first and second embodiments, if the calculated index of the corresponding pixel in the original image, P_I, is not an integer value image interpolation is used to obtain the pixel value at the appropriate pixel location.

[0034] As is known in the art, the methods and apparatus discussed herein may be distributed as an article of manufacture that itself comprises a computer-readable medium having computer-readable code means embodied thereon. The computer readable program code means is operable, in conjunction with a computer system to carry out all or some of the steps to perform the methods or create the apparatuses discussed herein. The computer-readable medium may be a recordable medium (e.g., floppy disks, hard drives, compact disks, or memory cards) or may be a transmission medium (e.g., a network comprising fiber-optics, the world-wide web, cables, or a wireless channel using time-division multiple access, code-division multiple access, or other radio-frequency channel). Any medium known or developed that can store information suitable for use with a computer system may be used. The computer-readable code means is any mechanism for allowing a computer to read instructions and data, such as magnetic variations on a magnetic medium or height variations on the surface of a compact disk.

[0035] It is to be understood that the embodiments and variations shown and described herein are merely illustrative of the principles of this invention and that various modifications may be implemented by those skilled in the art without departing from the scope and spirit of the invention.

What is claimed is:

1. A method for adjusting an image, comprising:

determining a viewing location of a viewer of said image; and

adjusting said image to compensate for a viewing location outside a predefined viewing range.

2. The method of claim 1, wherein said viewing location is outside a predefined viewing angle range.

3. The method of claim 1, wherein said viewing location is outside a predefined viewing distance range.

4. The method of claim 1, wherein said adjusting step further comprises the step of mapping pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

5. The method of claim 4, wherein said linear transformation morphs said image to compensate for an offset viewing angle.

6. The method of claim 4, wherein said linear transformation scales said image to compensate for a viewing distance outside said predefined viewing distance range.

7. The method of claim 4, wherein said mapping of pixels to a new image space creates an image with a greater number of pixels using an interpolation technique.

8. A method for adjusting an image, comprising:

determining a viewing location of a viewer of said image; and

mapping pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

9. The method of claim 8, wherein said viewing location is outside a predefined viewing angle range.

10. The method of claim 8, wherein said viewing location is outside a predefined viewing distance range.

11. The method of claim 8, wherein said mapping morphs said image to compensate for an offset viewing angle.

12. The method of claim 8, wherein said mapping scales said image to compensate for a viewing distance outside said predefined viewing distance range.

13. The method of claim 8, wherein said mapping of pixels to a new image space creates an image with a greater number of pixels using an interpolation technique.

14. A system for adjusting an image, comprising:

a memory for storing computer readable code; and

a processor operatively coupled to said memory (160), said processor configured to:

determine a viewing location of a viewer of said image; and

adjust said image to compensate for a viewing location outside a predefined viewing range.

15. The system of claim 14, wherein said processor is further configured to map pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

16. The system of claim 15, wherein said new image space has a greater number of pixels obtained using an interpolation technique.

17. A system for adjusting an image, comprising:

a memory for storing computer readable code; and

a processor operatively coupled to said memory (160), said processor configured to:

determine a viewing location of a viewer of said image; and

map pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

18. The system of claim 17, wherein said new image space has a greater number of pixels obtained using an interpolation technique.

19. An article of manufacture for adjusting an image, comprising:

a computer readable medium having computer readable code means embodied thereon, said computer readable program code means comprising:

a step to determine a viewing location of a viewer of said image; and

a step to adjust said image to compensate for a viewing location outside a predefined viewing range.

20. An article of manufacture for adjusting an image, comprising:

a computer readable medium having computer readable code means embodied thereon, said computer readable program code means comprising:

a step to determine a viewing location of a viewer of said image; and

a step to map pixels in said image to a new image space using a linear transformation that creates a distorted image such that when said distorted image is viewed from an offset viewing location said image appears as if being viewed from a direct viewing location.

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